THIRD YEAR'S COURSE IN PRACTICAL PHYSICS

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A THIRD YEAR'S COURSE IN PRACTICAL PHYSICS

(LIGHT)

BY THE SAME AUTHOR

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Third Edition, Revised

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A THIRD YEAR'S COURSE IN PRACTICAL PHYSICS

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PREFACE

THE present volume is the third of a series of elementary handbooks on Practical Physics. The aim throughout has been to set forth the instructions to the pupils in such a simple and clear way that they may be able to perform the experiments and understand the results with a minimum of work by the teacher. On the other hand, the theoretical part of the subject has been left almost entirely to the teacher, although in the present book a few proofs are added which should be understood by pupils in the third year of a science course.

Optics is such a wide subject that only a small part can be taken in a year's course, and the difficulty is to select the most suitable sections. Those chosen may be classed, with the exception of Chapters I. and II., under the term Pin Optics. The apparatus required is of the simplest—a few plane mirrors, curved mirrors, lenses (ordinary spectacle glasses do very well), and prisms. A cheap form of holder for the mirrors and lenses is shown on p. 39. Made of thin metal, this holder can be bent to hold lenses from about 1 to 5 cm. diameter. An optical bench is not required for any of the experiments.

Chapters I. and II. may be taken at the beginning of the session or left till the end. The experiments described in these two chapters are easy and interesting, and form a good introduction to the subject of light.

"Dispersion of Light" is merely touched, as a spectroscope is required for the majority of the experiments, and it is too much to expect a school laboratory to be provided with sufficient spectroscopes for a class of eighteen to twenty pupils. A few simple experiments, however, are given which may be performed with a simple prism.

For those pupils who wish to continue the study of Light on the same lines, the best book is "Practical Exercises on Light," by R. S. Clay, Esq., B.A., D.Sc. I am indebted to Dr Clay for permission to use Experiments 36, 41 (third method), 44 (second method); and for the pin methods of Experiments 47, 48, and 49. I have also to thank D. E. Jones, Esq., B.Sc., for permission to use Experiment 5. Experiments which have appeared in two or more text-books without acknowledgment I have presumed to be common property and have used them accordingly.

The proof sheets and the answers to the examples have been carefully corrected by my colleague, Mr G. W. M'Allister, M.A.

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THIRD YEAR'S COURSE

IN

PRACTICAL PHYSICS

CHAPTER I

PROPAGATION OF LIGHT

EXPERIMENT 1

To show that Rays of Light travel in straight Lines[1]

Apparatus—*Two sheets of stiff Opaque Cardboard; Two Clamp Stands; Candle; Thread*

MEASURE the length of the candle to the tip of the wick. At the same distance from the bottom edge of the sheets of cardboard make a pin hole (1 mm. diameter) in each sheet.

Place the sheets vertical and parallel about 30 cm. apart, and fix them in clamp stands so that the bottom edges are resting on the bench.

Light the candle. Run a thread through the two holes, and pull it straight. Place the candle so that the thread, after passing through the two holes, passes through the flame. The two holes and the candle are now in a straight line.

Take away the thread. Look at the flame through the two holes. Is it visible? Shift.the candle a little to one side so that the candle is not in a line with the two holes. Look through the two holes. Is the flame visible? Place the candle at various positions not on the line of the thread, and

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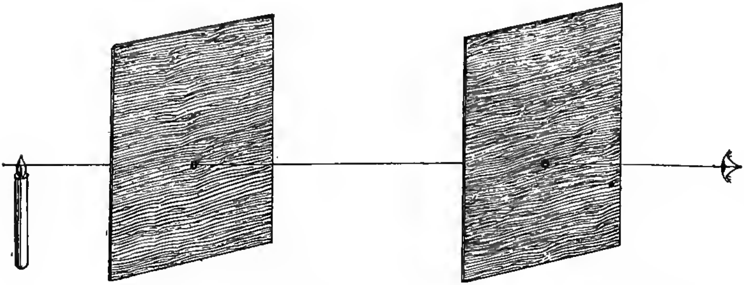
[1] This experiment should be performed in a darkened room.



look if the flame is visible through the holes. What is the inference?

Note.—A *Ray* is the line or direction in which light travels. A number of rays is called a *pencil* or *beam* of light. When rays of light proceed from a point in all directions they are called *divergent*, and when they approach one another they are called *convergent*.

EXERCISES

1. Three plates have a pin hole in each. It is required to arrange them so that the pin holes are in a straight line. How could you do this without using a piece of thread?

2. Bodies which allow rays of light to pass through them are called *transparent*; those which stop the rays are called *opaque*. Some bodies allow rays to pass through them to some extent, but an object cannot be seen distinctly through them. Such bodies are termed *translucent*. State whether the following bodies are transparent, opaque, or translucent:—sheet glass, ground glass, wax, paper, cardboard, oiled paper, gold leaf, milk, ink, water, the sea, china ware, mica.

EXPERIMENT **2**

To show that Rays of Light travel in straight Lines [Formation of Shadows][1]

Apparatus—*Bunsen Burner*; *Drawing-board with sheet of Paper pinned on it to form a Screen*; *Clamp Stand*; *Sheet of Cardboard* 8 *or* 10 *cm. square*; *Metre Stick or lath*

Screw off the tube from the bunsen burner, and light the burner at the small jet. Turn down the flame till it is very small.

Place the drawing-board screen upright on the bench, and set the flame about one metre in front of it.

Clamp the sheet of cardboard vertically in a stand, and place it between the screen and the flame. Move the clamp stand till the cardboard is parallel to the screen and till a shadow of the cardboard appears on the screen. What is the shape of the shadow?

Place a metre stick or a long lath so that it touches one corner of the cardboard and the corresponding corner of the shadow. Does the metre stick pass near the flame? If straight lines were drawn from the flame past and touching the edges of the cardboard, would these lines pass near the shadow?

Measure the perpendicular distance of the cardboard and of the screen from the flame, also the length of the cardboard and of the shadow (measured from corresponding points).

Alter the position of the cardboard by moving it backward or forward, and repeat the measurements. Do this several times, and arrange your answers in a table.

---

[1] This experiment should be performed in a darkened room.

Distance of Cardboard from Flame	Distance of Shadow from Flame	Length of Cardboard	Length of Shadow	$\frac{\text{Distance of Cardboard}}{\text{Distance of Shadow}}$	$\frac{\text{Length of Cardboard}}{\text{Length of Shadow}}$

EXERCISES

1. Set up the apparatus of the experiment, and turn up the flame till it is several centimetres long. Is the edge of the shadow as sharply defined as before? Give a reason for the difference.

2. In the cardboard of the apparatus cut a square hole about 3 cm. side, and arrange the apparatus as in the experiment. What do you notice on the screen? Compare the relative areas of the hole and the bright patch with the *square* of their relative distances from the flame.

3. A piece of cardboard with a square hole 2 inches side is placed 2 feet from a small flame. What is the area of the bright square seen on a vertical screen set parallel to the cardboard and 4 feet from the flame?

4. A small flame is 5 cm. from a piece of cardboard and 12·5 cm. from a screen. The height of the cardboard is 3·2 cm. What is the height of the shadow?

5. A vertical stick 10 in. high, set in front of a small flame, casts a shadow 25 in. high on a screen. The distance between the stick and the screen is 1 foot. How far is the stick from the flame?

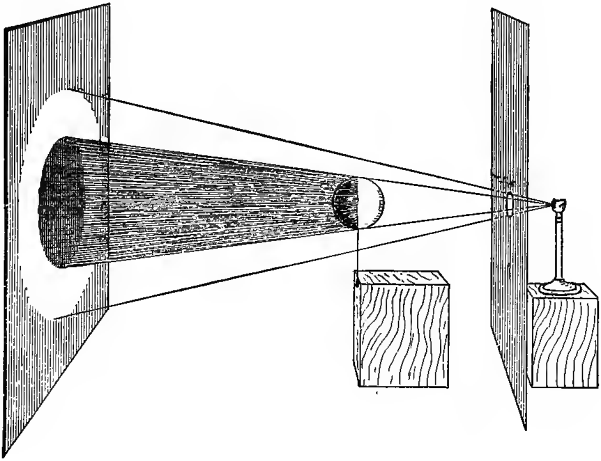
6. What is the shape of a pencil of rays proceeding from a point of light when the point is at (1) a finite distance; (2) an infinite distance?

EXPERIMENT 3

To show how Shadows are formed

Apparatus—*Large sheet of Opaque Cardboard*; *Fish-tail Gas Flame*; *Screen*; *Wood Spheres*; *Wood Blocks*; *Needles*; *Clamp Stands*

Fix a sheet of opaque cardboard vertically in a stand, and set the flame broadside behind it. Make a round hole about 2 cm. diameter through the cardboard at the height of the flame.



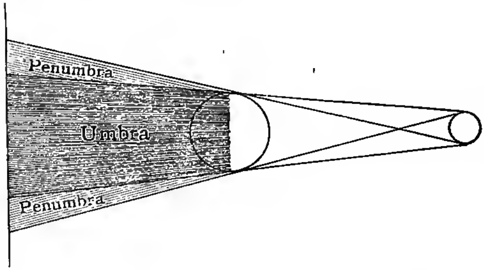
Place a receiving screen parallel to the cardboard and about half-a-metre away from it.

Fasten a drawing pin in one side of a block of wood near to the top, and between the block and the drawing pin fix a needle with point upward. On this needle fix a small wood sphere.

Turn the flame to a peep, and notice the shape of the bright patch on the screen. Into the beam of light bring the wood sphere. What happens? What is the shape of the shadow? Has all the shadow the same depth?

Move the sphere towards the receiving screen. What change is there in the shadow?

Turn the flame up. Its shape should be almost circular and broadside to the hole. What is the shape of the shadow? Is the shadow different from what it was when the light was small? The deep shadow is called the *umbra*, the lighter shadow the *penumbra*. Can you account for the different depths of shadow? (See diagram.) As the sphere is moved towards the receiving screen, what happens to the shadow?



Make a pin hole in the receiving screen—(1) in the centre of the *umbra*; (2) in the *penumbra*, and look through at the flame. Describe what you see.

EXERCISES

1. A very small flame is set a few feet in front of a screen. A ball is placed between the flame and the screen, touching the screen. The ball is moved slowly towards the flame. Describe the changes in the shadow, illustrating by diagrams.

2. Show by a drawing the cause of (1) an eclipse of the moon; (2) an eclipse of the sun.

3. Hold your pen between a sheet of paper and the window, the pen being close to the paper. Move the pen away from the paper. What happens to the shadow? Why?

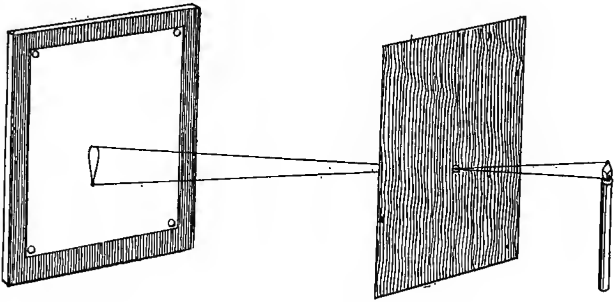
4. A penny is held (1) edgeways, (2) broadways between a small flame and a screen. What is seen on the screen? Would there be any difference if the flame were large?

EXPERIMENT **4**

To show that Rays of Light travel in straight Lines [Formation of Images][1]

Apparatus — *Drawing-board or Cardboard Screen*; *Large sheet of Opaque Cardboard*; *Candle or other Luminous Flame*; *Clamp Stands*; *Dividers*; *Metre Stick*

Place the sheet of cardboard and the screen vertical and parallel about half-a-metre apart. Place the flame a few centimetres from the cardboard on the side remote from the screen. (Shield the flame from draughts.)



Make a pin hole (1 mm.) through the cardboard at the level of the middle of the flame. What is seen on the screen? Why is the image inverted?

Measure the height of the luminous part of the flame and of the image with a pair of dividers. (Be careful to measure from corresponding points.)

Measure the distance of the flame and of the image from the hole, and arrange your answers in a table.

---

[1] This experiment should be performed in a darkened room.

Height of Object	Height of Image	Distance of Object from Hole	Distance of Image from Hole	$\frac{\text{Height of Object}}{\text{Height of Image}}$	$\frac{\text{Distance of Object}}{\text{Distance of Image}}$

Move the flame (1) nearer the hole; (2) away from the hole. In each case measure the height and the distance of the flame and the image.

Make another pin hole in the sheet of cardboard about 2 mm. from the first hole. What is seen on the screen?

Make a third hole near the other two so as to form a triangle (.·.). Describe the appearance of the images.

Now make the third hole double the size of the others. Is there any change in the images?

Make two or three other pin holes near the first ones. Are the images as distinct as before?

Is there an image for each hole?

Now make all the holes into one large hole. What is the shape of the image?

Make sketches to show the paths of the rays in each case.

Can you now explain why the clear image of an illuminated object which is formed by means of a pin hole becomes indistinct when the hole is enlarged?

EXERCISES

1. Arrange the apparatus as in the experiment, having one hole in the cardboard. Instead of one candle place three

lighted candles on blocks, one being higher than the others, thus (.˙.). Note the position of the images.

2. On the ground beneath a tree with dense foliage you will often see bright patches of a round or oval shape. It has been noticed that these patches are seen only when the sun is shining. Can you explain how the patches are formed?

3. A piece of glass consists of three horizontal strips, red, blue, and green. The glass is set vertically with the red strip at the top in front of a screen with a pin hole. The glass is illuminated by a candle set behind it. If a vertical screen is placed behind the pin hole, describe what will be seen on it.

4. An electric lamp has a filament $1\frac{1}{2}$ in. long. The lamp is covered with an opaque shade, but there is a small hole in this, and so a bright image of the filament is seen on a wall 2 feet away from the shade. The length of the image is 6 inches. How far is the shade from the filament?

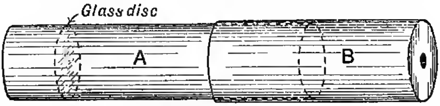
EXPERIMENT **5**

To make a Pin-hole Camera

Apparatus—*Two sheets of stout Paper, say* 9″ × 6″, *blackened if possible; Ground Glass Disc* 2″ *or* 3″ *diameter*

Blacken one side of a sheet of paper with ink or paint, and roll it into a cylinder (black side inward) having the same diameter as the glass disc. Gum the edge of the cylinder to keep it in shape, and lay aside to dry.

Blacken one side of another sheet of paper, and roll it round the first cylinder so that you have one cylinder (A) sliding inside another (B). Gum the edge of this second cylinder B to keep it in shape.



Fit the glass disc into one end of the cylinder A. If you have made the cylinder correctly the disc should fit exactly. Push the disc gently into the cylinder till it is about 1 inch from the end.

Cut a circle of thick opaque cardboard the same diameter as cylinder B, and make a pin hole in the centre of the cardboard. Fit the cardboard across the end of cylinder B which is farther from the glass disc. The camera is now complete.

Point the cardboard end of the camera at a flame, and look at the glass screen. What do you see? Is the image erect or inverted, enlarged or diminished? Slide cylinder B outward or inward, and notice any difference in the image. Why is it better to place the glass disc a little inside cylinder A and not at the outer end?

EXERCISES

1. A pin-hole camera can be made from an old chalk-box. Remove one end, and cover the opening with a piece of tissue paper or a piece of ground glass. In the middle of the opposite end bore a small hole with a red-hot needle. Blacken the inside of the box with ink or paint, and fill up any holes with putty.

2. The distance between the pin hole and the screen of a pin-hole camera is 10 inches. The height of the image of a stick 5 feet away is 3 inches. What is the height of the stick? [Solve by calculation and by drawing to scale.]

3. A flame 5 cm. high is 1 metre from the pin hole of a camera. The inner tube is drawn out till an image 1 cm. high is seen on the glass disc. What is the distance between the pin hole and the disc?

CHAPTER II

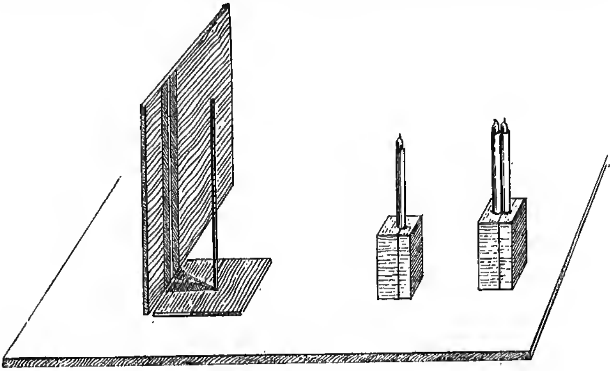
PHOTOMETRY

EXPERIMENT 6

To find the Relation between the Illuminating Power and the Distance of Sources of Light [Rumford's Shadow Photometer][1]

Apparatus—*Drawing-board Screen covered with White unglazed drawing Paper*; *Retort Stand without Rings*; *Three* Standard *Candles*; *Blocks of Wood*; *Metre Stick*

FIX the board vertically near one end of the bench, and place the retort stand a short distance (about 10 cm.) in front of it.



Fix a candle upright on a block by heating its lower end for a second, and two candles on another block, so that the three candles are of the same level. [The candles may be cut the same length and placed on the bench, in which case the blocks are not required.] Draw lines on the blocks opposite the centre of the flame of the one candle and midway between the flames of the two candles [see diagram].

---

[1] This experiment should be performed in a darkened room.

For Experiments 6, 7, and 8, which can be performed at the same time, the class should be divided into three sections, each section leaving the apparatus in position for the others.

Light the candles, and place the one candle about half-a-metre in front of the stand, so that a shadow of the rod is thrown on the screen.

Place the other two candles so that the flames are in a straight line with the rod.

Arrange the blocks so that the two shadows of the rod just touch. If one shadow is deeper than the other, move the light which causes the deeper shadow farther from the rod till the shadows are of the same blackness.

Measure the distance between a point on the screen (or the shadow) and the line on each block (*i.e.* the candle flame).

Change the position of the one candle, and move the two candles till the shadows are again of the same depth. Measure as before.

Repeat several times at various distances, and arrange your answers in a table.

Distance of 2 Candles from Screen	Distance of 1 Candle from Screen	(Distance of 2 Candles)^2	(Distance of 1 Candle)^2	$\frac{(\text{Distance of 2 Candles})^2}{(\text{Distance of 1 Candle})^2}$

Since the candles are *standard* candles, the flame of each gives the same amount of light, so the two candles will give double the amount of light (*i.e. illuminating power*) given by the one candle. [See table at end of book.] The quantity of light received on a unit of surface is called the *intensity* of illumination.

Since the two shadows on the screen are of equal depth, the screen is said to receive equal amounts of light (*i.e.* equal *illumination*) from the one candle and the two candles, so you would expect the two candles to be farther from the screen than the one candle. What is the relation between the illuminating powers of the candles and their distances from the screen?

This relation is called the *Law of Inverse Squares.*

The law can also be expressed in this way—The intensity of illumination varies inversely as the square of the distance. Thus if a candle is placed 1 foot from a screen, and then removed to 3 feet, the intensity in the first case would be 9 times that in the second.

Why do you measure from the shadow or screen and not from the rod? (The two shadows are of the same depth therefore the screen must be equally illuminated by both lights). Would it make any difference if the rod were placed farther from the screen?

EXERCISES

1. On one block one candle is placed and on another block three candles equal to the first. The two shadows cast by them on a screen are of equal depth. The one candle is 4 cm. from the screen. What is the distance of the three candles?

2. A lamp and a standard candle cast equal shadows on a screen. The distance of the candle is 5 cm. and the distance of the lamp 20 cm. Find the candle power of the lamp.

3. Two screens are placed at 50 cm. and 75 cm. respectively from a flame. Compare the illumination of the screens.

4. A candle is placed 1 foot from a screen, and four candles equal to the first are placed together on the other side of the screen, so that the screen is equally bright on both sides. How far are the four candles from the screen?

5. An electric lamp is of unknown candle power. A 16 candle-power lamp is 6 feet from a wall. The unknown lamp is moved till the two shadows cast by a chair on the wall are of the same darkness. The distance of the unknown lamp from the wall is 3 feet. What is its candle power?

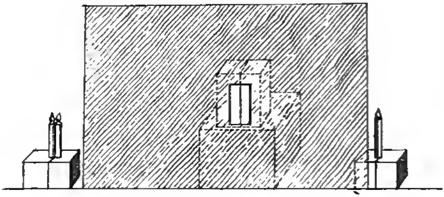
6. Construct a graph, using the numbers in Column 1 as the abscissæ, and those in Column 2 as the ordinates.

EXPERIMENT 7[1]

To find the Relation between the Illuminating Power and the Distance of Sources of Light [Joly's Paraffin Wax Photometer]

Apparatus—*Photometer consisting of two equal Blocks of Paraffin Wax* (4 *cm.* × 4 *cm.* × 1 *cm.*) *joined with gum along one broad surface with a square* (4 *cm.* × 4 *cm.*) *of Tin Foil between them*; *Large sheet of thick Cardboard* (*blackened if possible*); *Metre Stick*; *Blocks*; *Three Standard Candles*

Draw a chalk line on the bench, and near the middle of it place a block of wood. On the block place the photometer with the plate of tin vertical and at right angles to the chalk line.



Place one candle on the chalk line and two candles together on the chalk line on the other side of the photometer. Arrange the heights of the candles with blocks so that the flames and the middle of the photometer are at the same height.

In front of the photometer place the large sheet of cardboard upright so that the end of the photometer is in contact with it. Cut a hole in the cardboard 3 cm. long and 1 cm.

---

[1] This experiment should be performed in a darkened room.

broad opposite the photometer so that the edge of the tin and a part of each paraffin block can be seen.

Light the candles, and look at the photometer through the hole. What do you notice about the two parts of the photometer?

Look at the photometer, and gradually move the flame on the darker side nearer the photometer till the two parts appear the same. This is easily done, for the dark side suddenly becomes bright if the candle is moved too near.

Measure the distances between the candles and the tin foil. [In the case of the two candles take the average distance.]

Repeat with the candles at different distances, and arrange your answers in a table as in the last experiment.

Note.—The purpose of the cardboard is to shield the eyes from the light of the candles, so, in looking at the photometer, keep your eye near to the cardboard.

EXERCISES

1. One candle is 20 cm. from the photometer, and a second candle, equal to three of the first, is 50 cm. from the other side of the photometer. Which side of the photometer is the brighter?

2. Two lights, one a 9 candle-power lamp and the other a 16 candle-power lamp, are 7 feet apart. Where must a paraffin wax photometer be placed on the line joining them so that the blocks of wax will be equally bright?

EXPERIMENT **8**[1]

To find the Relation between the Illuminating Power and the Distance of Sources of Light [Bunsen's Grease Spot Photometer]

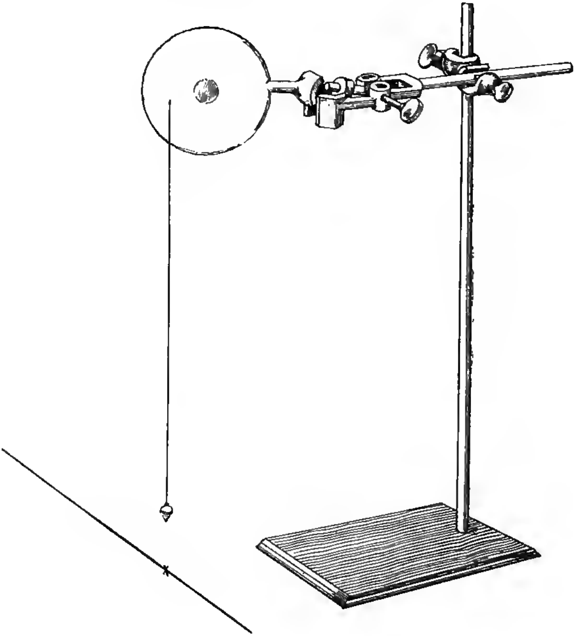
Apparatus—*Clamp Stand with Ring*; *Sheet of unglazed Paper* (e.g. *drawing paper*); *Thread*; *Metre Stick*; *Standard Candles*

Cut a square of unglazed paper about 2 inches longer than the diameter of the ring of the stand. Fix this sheet across the ring by turning over the edges or by gumming the ring and stretching the paper over it, so as to form a screen.

---

[1] This experiment should be performed in a darkened room.

On the centre of this screen let a drop of grease fall from a standard candle. Scrape the grease off with a knife when it is cold. Heat the knife for a second in a bunsen flame, and press the grease spot on both sides with the hot knife till the grease has soaked well through the paper.



Hold the screen up (1) in front of a window; (2) before a dark object. What is the appearance of the spot? Can you explain?

Make a pin hole through the screen at the side of the grease spot. Pass a thread (a few inches long) through the hole, and make a knot at one end. To the other end attach a little bit of wax. This thread forms a plumb-line.

Draw a chalk line along the bench, and mark a point near the middle.

Fix the screen vertically in the clamp of the stand so that the screen can be turned round, with the clamp as a horizontal axis (as in diagram).

Place the screen so that the grease spot is exactly opposite the chalk mark, the screen being at right angles to the line. This is done by placing the plumb-line above the chalk mark.

Fix a standard candle on a block and two standard candles on another block. Place the blocks on the chalk line on each side of the screen, and fix the grease spot and the flames at the same height.

Look at the grease spot from the left side, the eye being in a line with the spot and the flame (stand well back from the flame). If the spot appears dark, move the light on the left side farther from the screen; if the spot appears bright, move the same light nearer the screen till the grease spot becomes invisible.

Look at the spot from the other side of the screen, the eye being in a light with the flame and the spot. In theory the spot should be invisible, but in actual experiments it usually can be seen faintly, as the rest of the screen is not absolutely opaque.

To get the distances of the flames when the spot is as invisible as it can be, proceed as follows:—

(1) Adjust the candle on the left side till the spot is invisible when viewed from the left side. Measure the distance from the left-hand candle to the screen.

(2) Turn the screen round on the clamp through an angle of 180°—*i.e.* the opposite side of the screen faces the left-hand candle—and place the plumb-line again over the chalk mark. Adjust the left-hand candle (if necessary) till the spot is invisible from the left-hand side. Measure the distance of the left-hand candle from the screen.

(3) Take the average of (1) and (2) as the distance of the left-hand candle.

(4) Keep the left-hand candle fixed and repeat (1), (2), and (3) for the right-hand candle.

Place the candles at various distances, and repeat the experiment.

Arrange your answers in a table as in the previous experiments.

EXERCISE

In an experiment it was found that the grease spot was invisible from the left-hand side when the left-hand light was at a distance of (1) 25·2 cm., (2) 25·6 cm., while the corresponding distances of the right-hand light were (1) 36·4 cm., (2) 35·8 cm. Compare the powers of the flames.

EXAMINATION PAPER ON EXPERIMENTS 1-8

1. Explain how it is that when the rays from a flame pass through a hole and reach a screen, an image of the flame is seen when the hole is very small and a bright patch when the hole is not small. What is the shape of the patch?

2. How would you use a pin-hole camera to find the height of a tree? A tree 30 feet away has an image 6 inches high on the screen of a camera, the distance between the screen and the hole being 1 foot. Find the height of the tree.

3. Where would you place a rod before a screen so as to get the darkest image? What happens when the rod is moved away from the screen? Why, in this case, is the whole image not of equal darkness?

4. What do you mean by the illuminating power of a flame? What relation is there between the power of a flame to illuminate a screen and the distance of the flame from the screen?

5. What do you mean by the candle power of a flame? Describe exactly how you would use Bunsen's Photometer to find the candle power of a flame.

6. A 6 candle-power lamp is 2 feet in front of one side of a screen, and a 10 candle-power lamp is 3 feet in front of the other side. Which side of the screen is better illuminated?

7. A candle is placed 1 foot in front of the screen, and an

equal candle 2 feet in front of the screen. The two candles are then placed together at 18 inches from the screen. Is there any difference in the illumination of the screen?

8. What is the principle of Rumford's Photometer? A candle is placed 30 cm. in front of a rod ·5 metre high, and a shadow is cast on a screen 5 cm. behind the rod. What is the length of the shadow?

9. What is a shadow? How can you prove by means of shadows that rays of light travel in straight lines?

10. What do you mean by "luminous body," "transparent body," "translucent body," "opaque body"? Give some examples.

CHAPTER III

REFLECTION FROM PLANE SURFACES

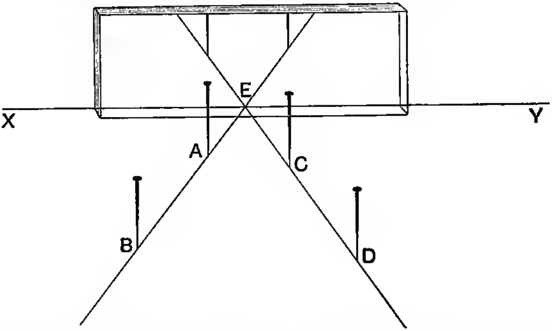
EXPERIMENT 9

To study the Laws of Reflection

Apparatus—*Thin Mirror about* 6″ × 1″ [1]; *Sheet of Paper*; *Pins*; *Protractor*

Fix a sheet of paper on the bench, and draw a straight line XY across the middle of the paper.

Place the mirror vertically so that the silvered back or the reflecting surface is along XY. [If the mirror will not stand, a pin behind it and one in front of it at one end will support it.]



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[1] Instead of a silvered mirror a rectangular slab of plain glass may be used for this and succeeding experiments. One broad side is blackened, while the opposite side acts as a mirror. To blacken one side, soak a piece of blotting paper in turpentine, set fire to it (or set fire to a piece of camphor), and hold the slab in the smoke. This slab is better than the silvered mirror, because there is no refraction.

Stick a pin A upright in front of the mirror about 1 cm. from it, and another pin B several cm. from A in an oblique direction to the mirror, so that a line passing through A and B would if produced meet the mirror. Draw this line BA.

Look along this line BA so that the *foot* of the pin A is hidden by the *foot* of the pin B, and while looking stick a pin C a little in front of the mirror so that the pins B, A, and the *image* of C are in a straight line.

Again look along BA, and place a fourth pin D several centimetres in front of the mirror so that the pins B, A, and the images of C and D are in a straight line.

Keeping the pins in position, draw the line DC. Look along DC. What are in a straight line?

Remove the mirror and the pins. Produce the lines BA and DC till they meet at E. Where is E from XY?

From E draw a line EF at right angles to XY. This line EF is called the *Normal.*

Measure the angles BEF and DEF with a protractor or compasses. Are they equal? If we suppose a ray of light to travel along BA and to be reflected or driven back from the mirror at E along CD, then the angle BEF is called the *Angle of Incidence*, and the angle DEF the *Angle of Reflection.* Measure also the angles XEB and YED.

Notice that the line BA (called the *Incident Ray*), the normal EF, and the line CD (called the *Reflected Ray*) are in the same plane—*i.e.* the plane of the paper.

Shift the position of the pins A and B, repeat the experiment several times, and in each case measure the angle of incidence and the angle of reflection. Are they always equal to each other?

Gum the sheet of paper on the left-hand page of your book.

If the line BA is at right angles to the mirror, where will C and D be placed? In this case the ray BA is said to reach the mirror *normally.* Therefore a ray reaching a mirror normally is reflected back along the same path.

The *Laws of Reflection* are:

1. The Angle of Reflection is equal to the Angle of Incidence.
2. The Incident Ray, the Normal, and the Reflected Ray are in the same plane.

EXERCISE

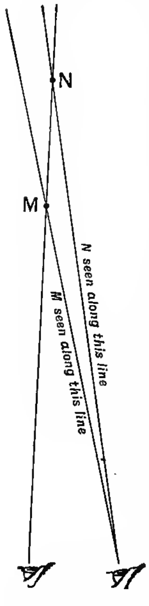
Two parallel rays strike a mirror. Prove that the reflected rays are parallel.

EXPERIMENT **10**

To find the Position of an Image in a Plane Mirror

First Method

Apparatus—*Mirror* 6″ × 1″ ; *Pins* ; *Sheet of Paper*



(1) Hold your pencil vertically between one eye (shut the other eye) and an object. Keeping the pencil steady, move your head a little to the right or the left. How does the pencil seem to move relative to the object and to yourself? For example, if you move your head to the right, does the pencil appear to move to the right of the object, or to the left, or not move at all?

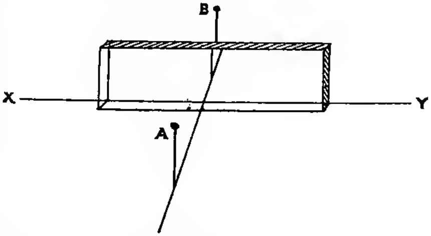
(2) Look through a window (with bars) at a distant object. Make a step to the right. How does the distant object appear to move relative to the bar of the window and to you?

(3) Look at two distant objects M and N (say trees or telegraph poles), which are nearly in a line with your eye. Move one step to the right. How do the objects move? Suppose that one of the objects (say M) moves more to the left than the other (N), which is the nearer? (See diagram.)

Can you now give the rule for finding which is the nearer of two objects nearly in a line with your eye? This method of finding which object is the nearer is called the method of *Relative Motion* or *Parallax*.

Fix a sheet of paper on the bench, draw a line XY across it, and set the mirror vertical, with the reflecting surface over XY. Stick a pin A upright a few centimetres in front of the mirror.

Look past A into the mirror at right angles to it, and with one eye (close the other eye) a little above the level of the top of the mirror, so that only the lower part of the image of the pin is seen in the mirror. Stick another pin B behind the mirror so that the upper part of B and the lower part of the image of A appear to be in a straight line.



You wish to find if B marks the position of the image of A. To do this move your head gradually to the right. If B and the image remain in a straight line, then B marks exactly the position of the image. If not, B is either too near or too far from the mirror.

Note how B has moved relatively to the image and yourself. From the rule you discovered above you should be able to state whether B or the image is the nearer.

Change the position of B by placing it nearer or farther away from the mirror as is required, and try as before.

After some attempts you will find a position where B and the image of A always appear in a straight line, no matter from what position you look at them. B then marks the position of the image of A.

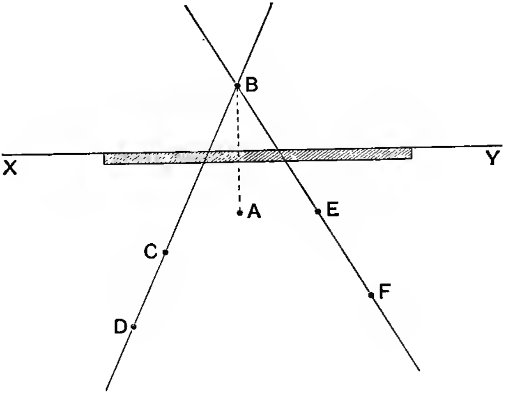
Remove the mirror, and join the positions of A and B by a straight line cutting XY in O. Measure AO, BO, and the angle AOX. State now the exact position of the image of any object, as seen in a plane mirror.

Second Method

Apparatus—*Same as for First Method*

Place the mirror on the line XY, and fix the pin A in the same position as in the First Method.

Stick a pin C a little to the left of A. Look into the mirror in such a position that C and the *image* of A are in a line with your eye (close one eye). While looking, fix a pin D between your eye and C, so that D, C, and the image of A are in a straight line. Then the image of A lies along DC produced.



In the same way fix two pins E and F to the right of A so that F, E, and the image of A are in a straight line.

Remove the mirror and produce the lines DC and FE till they meet at B. Then B is the position of the image. (Why?)

Join AB, cutting XY in O. Measure AO, BO, and the angle AOX.

Note.—When a surface is not perfectly smooth, rays of light are said to be irregularly reflected. For example, this page is easily seen because the surface of the paper is rough, consisting of innumerable points, and the light striking on them is reflected in all directions. Each single ray is reflected according to the laws of reflection, but as the paper consists of innumerable point-mirrors set in all positions, the rays are reflected in all directions. It is because of irregular reflection that we are able to see bodies distinctly.

EXERCISES

1. In the diagram of the First Method the eye has been moved to the right. Is B in front of or behind the image of A?

2. Place a pen over your left ear, and look into a mirror. Over which ear does the pen appear to be? Can you explain?

3. Place a page of writing in front of a mirror. Look in the mirror. Can you see the writing? On a sheet of paper print a capital P. Place the letter nearly at right angles to the plane of the mirror, and look obliquely into the mirror. Draw the letter as you see it in the mirror. The image of the letter is said to be *laterally inverted*. Hold a piece of used blotting paper in front of a mirror. Can you read any of the writing?

4. The number 137 is written on a sheet of paper and held up before a mirror. Draw the figures as seen in the mirror.

5. A pin is placed 7 cm. in front of a plane mirror. What is the distance between the pin and its image? The mirror is moved backward from the pin a distance of other 7 cm. What is now the distance between the pin and its image?

6. A man 6 feet high looks into a vertical mirror 3 feet high, the top of the mirror being on a level with the top of the man. The man sees his whole image. Explain by a diagram (drawn to scale) how this is possible. Is it possible when the mirror is less than 3 feet high?

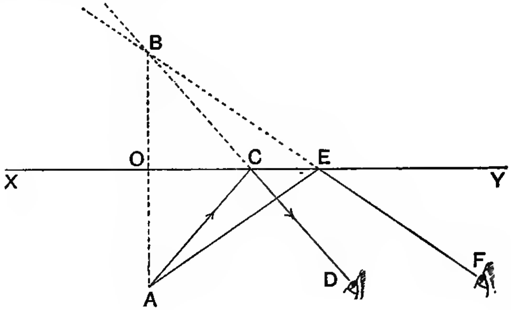
7. A mirror is inclined upward so that the reflecting surface is at an angle of 45° with the ground. A pencil is set vertically in front of the mirror. What is the position of the image? Draw a line to represent the inclined mirror, and so confirm the exercise by drawing.

EXPERIMENT 11

To find the Position of an Image (by Geometry)

Apparatus—*Straight-edge*; *Protractor*

Draw a line XY to represent the reflecting surface of a vertical mirror, and a point A to represent a pin in front of the mirror.



From A rays of light travel in straight lines to all parts of the mirror. Take any point C in XY and join AC. Then AC represents one ray from A to the mirror.

When the ray AC strikes the mirror at C it is reflected so that the angle of reflection is equal to the angle of incidence. Draw the reflected ray CD so that the angle YCD = angle XCA. A person at D sees the image of A somewhere along the line DC.

Draw any other ray AE and the reflected ray EF. A person at F sees the image of A somewhere along FE. Therefore the image of A will be at the intersection of DC and FE—*i.e.* at B.

Join BA, cutting XY at O. Measure OA, OB, and the angle BOC.

Prove by geometry that $BO = AO$ and $\angle BOC = 90^\circ$.

Note.—As rays from A strike all parts of the mirror, an eye placed anywhere in front of the mirror will receive more than one ray (since the eye has a definite size), therefore the image B will be seen by an eye placed at any position in front of the mirror.

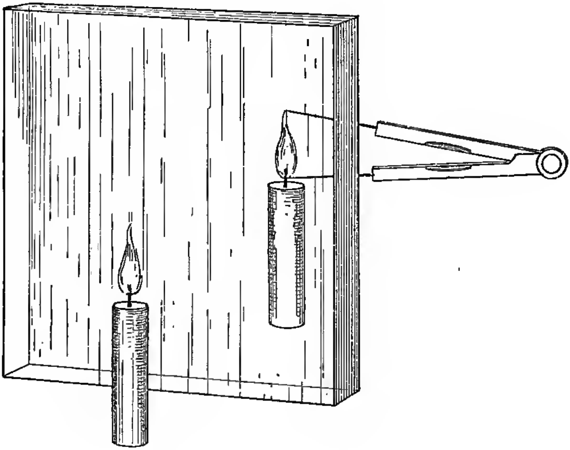
EXPERIMENT **12**

To compare the Size of an Object and its Image in a Plane Mirror

First Method

Apparatus—*Glass Slab*; *Candle*; *Pair of Dividers*; *Straight-edge*

Polish the glass slab and set it vertical on the bench. Place a lighted candle a few centimetres in front of one of the broad surfaces. Look normally into this broad surface and you will see a faint image of the flame.

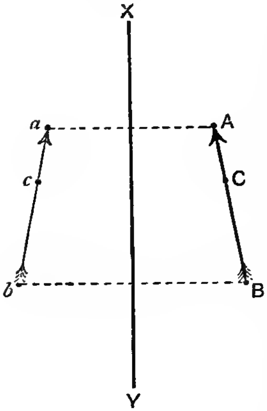


Place one leg of the dividers at the tip of the flame, and the other leg at the bottom of the luminous part. The distance between the points of the dividers is therefore equal to the height of the flame. Measure this height on the straight-edge.

Hold the dividers behind the slab. Look through the slab, and place the dividers so that one point is at the top of the image of the flame and the other point at the bottom. This gives the height of the image. What do you notice about the relative sizes of the object and its image?

Second Method

Apparatus—*Mirror* 6″ × 1″; *Sheet of Paper*; *Pins*



Draw a line XY on a sheet of paper, and set the mirror vertically over this line. On the paper a little in front of the mirror draw a line AB, and stick upright pins at A and B.

By the method of relative motion find the positions (*a*, *b*) of the images of A and B. Then the straight line *ab* will mark the position of the image of AB. To confirm this, stick an upright pin C at any point on AB. Find by the method of relative motion the position of the image *c*. Is *c* on the line *ab*?

Measure AB and *ab*, and compare their lengths.

EXERCISE

Prove that the position of the image of an object in a plane mirror is independent of the position of the observer.

EXPERIMENT **13**

To find the Number and Position of the Images formed by two Inclined Mirrors

Apparatus—*Two Mirrors* 6″ × 1″; *Pins*; *Gummed Paper*; *Protractor*; *Sheet of Paper*

Join a short edge of each mirror together with a piece of stout gummed paper so as to form a hinge.

Pin a sheet of paper on the bench, and on it draw a line AB. From A draw lines making angles of 90°, 72°, 60°, 45°, 40°, and 30° with AB.

Place the mirrors vertically so that the hinge is over A and one of the mirrors along AB. Fix this mirror by pins or nails in front and behind it at the free end. Place the second mirror at an angle of 90° with the first mirror.

Stick a pin upright between the mirrors about 3 or 4 inches from the hinge.

Get above the mirrors from behind, and looking down into the two mirrors, count all the separate images. Be careful that you do not omit any or count the same image twice.

Rotate the second mirror till the angle between the mirrors is a few degrees less than 90°. Note what has happened to the middle image.

Carefully rotate the second mirror till the angle between the mirrors is 72°, looking constantly at the images. Count the number of images at 72°.

Continue to rotate the second mirror a few degrees below 72°. Note the change in the number of images.

Place the mirrors at 60°, 45°, 40°, 30°, and count the images in each case, the pin always being placed midway between the mirrors.

Arrange your answers in a table. Is there any connection between the answers in Columns 3 and 4?

1	2	3	4
Angle between Mirrors	Number of Images	Number of Images + Object	$\frac{360^\circ}{\text{Angle between Mirrors}}$

Position of the Images

Place the mirrors inclined at 90°, and mark the position of each image by a pin, using the method of relative motion. Measure the distance between each image and the mirrors, compare with the distance of the object from the mirrors, and try to find a rule for getting the position of the images when the position of the object is known. Show that the images lie on the circumference of a circle. What is the centre and what the radius of the circle?

Repeat with the mirrors inclined at 60°.

As the angle between the mirrors decreases, what change is there in the number of images? When the angle between the mirrors decreases to 0° (*i.e.* when the mirrors are parallel), what will you expect the number of images to be?

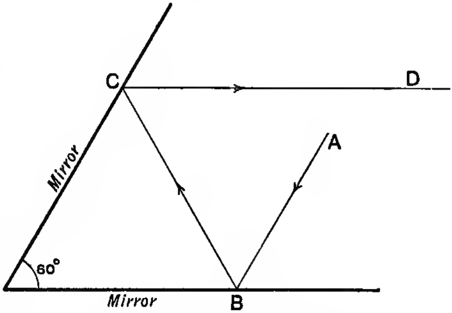
Exercises

1. How many images are seen when an object is placed between two mirrors inclined at 10°, 15°, 18°, 35°, 50°, 70°, 80°?

2. Place the two hinged mirrors at an angle of 120°, and see if the rule for the number of images, as found by the experiment, is true for angles greater than 90°. Try with other angles up to 180°. What happens when the angle is greater than 180°?

3. Draw two lines inclined at 60° to represent two mirrors.

Let AB be a ray of light which reaches one mirror in a direction parallel to the second mirror. At B the ray is reflected according to the laws of reflection, and reaches the second mirror at C. At C it is again reflected. Measure the angle of reflection at C. Confirm your answer by geometry.



Answer this question: What is the angle between two inclined mirrors when a ray, reaching the first mirror in a direction parallel to the second mirror, after two reflections is parallel to the first mirror?

4. Draw two mirrors inclined at 30°. Draw a ray striking one mirror in a direction parallel to the second mirror, and find if after several reflections the reflected ray becomes parallel to either of the mirrors.

5. Two mirrors are placed at right angles. A ray of light strikes one of the mirrors at any angle, is reflected to the second mirror, and again reflected. Prove by drawing and by geometry that the ray after this second reflection is parallel to its original direction.

6. Two mirrors are inclined at 45°. A ray strikes one at an angle of 22½°. Find by drawing and geometry the direction of the ray after four reflections.

7. In a tailor's shop mirrors are arranged so that a customer can see the image of his back. Sketch the position of the customer and the mirrors.

EXPERIMENT 14

Images in Parallel Mirrors

Apparatus—*Sheet of Paper*; *Two Mirrors* 6″ × 1″; *Pins*

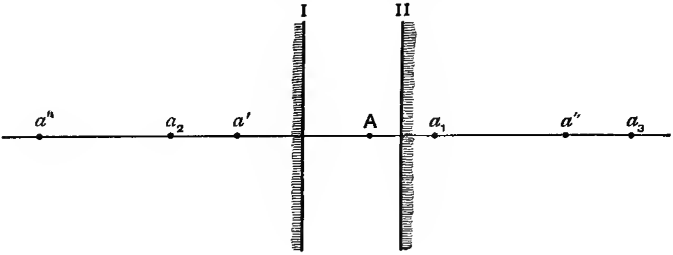
Pin a sheet of paper on the bench, and draw two parallel lines on it about 5 cm. apart. Place the mirrors vertically over these parallel lines.

Stick a pin between the mirrors, but nearer to one mirror than to the other. Look obliquely over the top of one mirror (near the end of it) into the other mirror. Count the number of images you can see. What do you notice about their position and their distinctness? Look now into the other mirror.

By the method of relative motion fix a pin in the position of the first image in one of the mirrors. Take out the pin, and mark its position with a number or letter. In the same way mark the positions of all the images in both mirrors.

Remove the mirrors, and see if the images are in a straight line.

Measure the distance of each image from the two mirrors. Is there any connection between your answers? [Each image forms a corresponding image in the mirror which faces it. Thus in the diagram, if A is the object, *a′* is the image formed



by A in mirror I. But a' is in front of mirror II, and forms an image a'' behind mirror II. Also a'' forms an image a''' behind mirror I. In the same way a_1 is the image of A in mirror II, a_2 is the image of a_1 in mirror I. and so on. a' and a_1 are called *primary* images, a'' and a_2 are called *secondary* images, a''' and a_3 *tertiary* images. As each image produces another image, the number of images should be infinite, but it is found that the images become less distinct the farther they are from the mirror, till beyond a certain point they cannot be seen.]

EXERCISES

1. Why is it that, on looking out of the window of a railway carriage, you can often see the objects outside and an image of the interior of the carriage at the same time?

2. Take a rectangular slab of glass, and polish the front and back faces. Set the slab vertical and place a lighted taper or candle about 1 cm. in front of a broad surface near the end. Look past the flame normally into the slab. How many images are seen? Compare their brightness. Now move your head along to the other end of the slab and look obliquely at the images. Is there any difference in the number or the brightness? Which is the brightest? Can you give any reason why there are several images?

Repeat the exercise with a silvered-back mirror having extra thick glass. How many images are seen? Which is the brightest? Blacken one broad surface of the glass slab, and repeat the exercise. How many images are now seen? Try the exercise with a thin mirror.

3. Two parallel mirrors are 6 cm. apart. A pin is placed between them 2 cm. from the left-hand mirror. Find the distances of the images from each mirror.

4. In some ball-rooms, the end walls are completely covered with huge mirrors. What is the effect of this?

5. A glass flame is enclosed in a lamp which consists of four vertical square sheets of glass in the shape of a box. How many primary and how many secondary images will be formed?

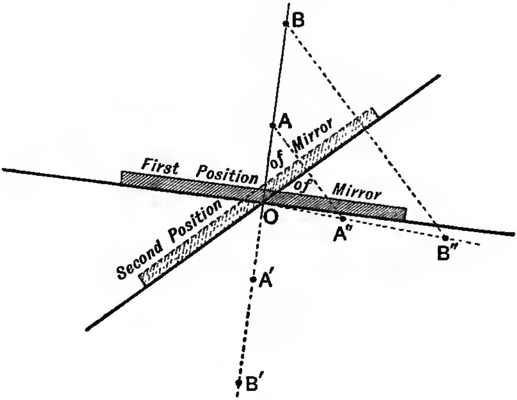
EXPERIMENT **15**

To study the Effect of rotating a Mirror round a Vertical Axis through its Centre

Apparatus—*Mirror* 6″ × 1″ ; *Pins* ; *Sheet of Paper* ; *Protractor*

Fix a sheet of paper on the bench, and draw on it two lines intersecting at O.

Along one of the lines place a mirror vertically, and from O draw a normal to the mirror. On the normal place two pins, A and B, upright.



Mark the position of the images A′ and B′, using the method of relative motion.

Turn the mirror round a vertical axis through O till it stands over the other line. Mark the position of the images A″ and B″.

Produce the lines B′A′ and B″A″ till they meet. Where do they meet?

Measure the angle through which the mirror has been turned (*i.e.* the angle between the intersecting lines) and the angle through which the image of the line AB has been turned (*i.e.* the angle between B′A′ and B″A″). Compare these two angles.

If BA is a ray striking the mirror (1) in its first position, (2) in its second position, how will it be reflected? Draw the reflected rays. Compare the angle between the two positions of the mirror and the angle between the two reflected rays.

EXERCISES

1. A horizontal ray of light strikes a vertical mirror at any angle. The mirror is rotated through an angle of 30° round a vertical axis through the point where the ray strikes the mirror. Find, by drawing, the angle through which the reflected ray turns.

2. A ray strikes a mirror obliquely and the mirror is turned so that the new reflected ray is at right angles to the former reflected ray. Find the angle through which the mirror has been turned.

EXPERIMENT **16**

To study the Effect of rotating a Vertical Mirror round a Vertical Axis at one End

Apparatus—*Mirror* 6″ × 1″; *Sheet of Paper*; *Pins*

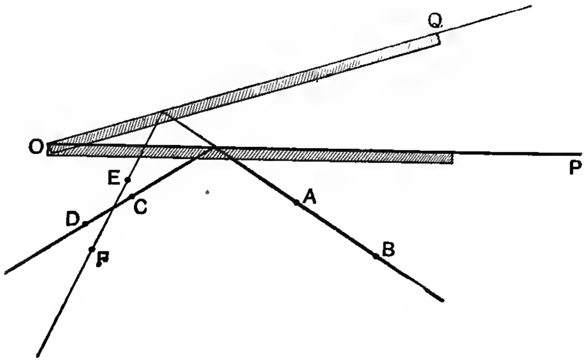
Pin a sheet of paper on the bench, and draw a line OP across it. Place a vertical mirror along OP so that one vertical edge is exactly over O.

Draw a line on the paper in front of the mirror to cut the mirror at any angle, and stick two upright pins A and B on this line. Then the line AB represents a ray of light which strikes the mirror.

Look obliquely into the mirror, and place two pins C and D so that C, D, and the *images* of A and B are in a straight line. Draw a line through CD. Then the line CD is the path of the reflected ray. Mark the position of the pins C and D and remove them.

Turn the mirror round O to any position OQ.

Place two pins E, F in front of the mirror so that E, F, and the images of A and B are in a straight line. Then EF is the reflected ray from the mirror OQ. Draw the line EF.



The angle between OP and OQ is the angle through which the mirror has been rotated. The angle between CD and EF is the angle through which the reflected ray has been rotated. Measure these angles, and compare them.

Note that this experiment might be written thus—"To find the effect of rotating a vertical mirror round a vertical axis through any point in the mirror other than the point where the ray reaches the mirror."

EXERCISE

Examine a simple sextant, and find the principle on which it is worked.

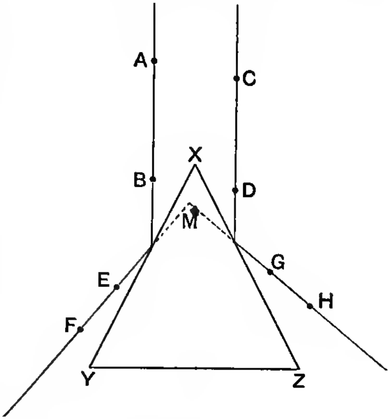
EXPERIMENT **17**

To find the Angle of a Prism

Apparatus—*Prism*; *Pins*; *Sheet of Paper*; *Protractor*

Fix a sheet of paper on the bench, and on it draw two short parallel lines 1 cm. to 2 cm. apart. On the left-hand line place two pins A and B upright two or three centimetres apart.

Place the prism on its triangular end so that the two faces forming the angle touch the end of the lines (see diagram), and draw a line XYZ round the bottom of the prism. Each of the faces of the prism forms a mirror.



Look into the face XY. You will see faint images of the pins A and B.

Place a pin E in front of XY so that E and the images of A and B are in a straight line.

Place another pin F farther from the mirror so that F, E, and the images of A and B are in a straight line.

Remove the pins A and B and place two pins C and D on the other parallel line. Look into the face XZ, and place two pins G and H in front of XZ so that H, G, and the images of C and D are in a straight line.

Remove the prism, and produce FE and HG till they meet at M.

The ray AB meets the mirror XY, and is reflected along FE.

The mirror XY may be supposed to be then rotated round X till it comes to the position XZ. The ray CD, which is in the same direction as the ray AB, meets XZ, and is reflected along GH.

The reflected ray is thus turned through the angle EMG. By Exp. 17 this is double the angle through which the mirror has been rotated—*i.e.* the angle YXZ.

Measure the angle EMG, and from this get the angle YXZ—*i.e.* the angle of the prism.

EXAMINATION PAPER ON REFLECTION

1. State the laws of reflection from a plane mirror. How would you prove them?

2. What is the principle of the method of relative motion for finding which of two distant objects is the nearer? How would you use this method to find the position of the image in a plane mirror?

3. What is meant by "lateral inversion"? Give any instances of it that you know.

4. A flame is placed 10 cm. in front of a mirror. The mirror and the flame are each moved 10 cm. back from their original positions. How far apart are the positions of the image?

5. Two mirrors are inclined at 90°. A ray strikes one of the mirrors at an angle of 45°. What is the direction of the ray after two reflections?

6. A candle is placed in front of a thick glass slab or mirror. Why is it that a person sees several images on looking obliquely into the slab?

7. Draw two parallel lines 3 cm. apart to represent two parallel mirrors, and mark a point 1 cm. from one line to represent a pin. Mark the positions of the images seen in the mirrors, and state any relation between these positions.

8. Two mirrors are inclined at 60°, and a pin is placed in front of them. Make a diagram of the arrangement, and mark the positions of all the images.

9. A ray of light from a point A falls on a mirror and is reflected to a point B. Show that the path of the ray from A to the mirror and then to B is the shortest possible.

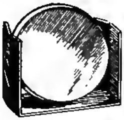
CHAPTER IV

REFLECTION FROM CURVED SURFACES

EXPERIMENT **18**

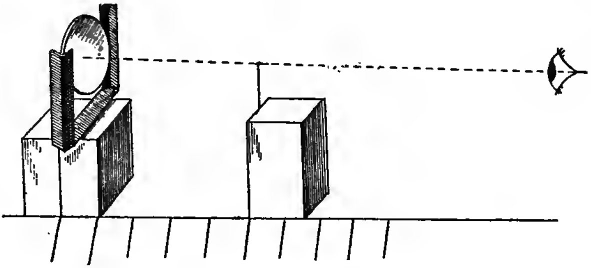
Reflection from Curved Mirrors [Spherical Concave]

Apparatus—*Concave Mirror* (*not more than* 10 *to* 15 *cm. focal length*); *Stand for holding Mirror*; *Blocks of Wood*; *Pins or Needles*; *Metre Stick*



DRAW a long chalk line on the bench, mark off centimetres on it (or lay a metre stick along the line), mark a point near one end of it, and place the mirror (set vertically in its stand) on a block of wood so that the centre of the reflecting surface is exactly opposite the chalk mark.

Stick a needle (or a pin) vertically, point upward, at the edge of a block of wood so that the point of the needle is on the same level as the centre of the mirror. (This may be done by sticking a drawing pin in the side of



the block and inserting the vertical needle (or pin) between the head of the drawing pin and the block.)

Place the needle at a distance of 1 cm. from the mirror. Look past the needle into the mirror, keeping your eye about half-a-metre away. [You will perhaps have difficulty in seeing the image of the needle because of your own image. If so, gradually remove the block with the needle away from the mirror till the image is clearly seen, and then slowly move the block back towards the mirror, keeping your eye on the image till the needle is 1 cm. from the mirror.]

Note if the image is distinct, if it is inverted, if it is larger or smaller than the needle.

By the method of relative motion find if the needle or the image is nearer your eye.

Place the pin 3 cm., 5 cm., 7 cm., etc., from the mirror, repeat your observations, and arrange the results in a table.

Distance of Needle from Mirror	Is the Image Distinct or Blurred?	Is the Image Larger or Smaller than the Needle?	Is the Image Erect or Inverted?	Which (the Needle or the Image) is nearer your Eye?

From the last column find the distance (roughly) at which the needle must be so that the image is at the same distance as the needle from your eye, and therefore from the mirror.

Place the needle at this distance from the mirror, and move it slightly till the needle and the image exactly coincide. [Use the method of relative motion.]

Measure the distance of the needle from the mirror. This distance is called the *Radius of Curvature* of the mirror—*i.e.* the mirror is part of the surface of a sphere with this radius. [See Exp. 20.]

EXERCISES

1. Describe the appearance, position, and size of the image of an object which is placed in front of a concave mirror (1) at a less distance than its radius of curvature; (2) at a greater distance.
2. Repeat the experiment with a convex mirror.

EXPERIMENT **19**

Real and Virtual Images

Apparatus—*Plane Mirror* (*say* 6 *inches* × 6 *inches*); *Toy Candle*; *Blocks of Wood*; *Sheet of stiff Paper or Cardboard*; *the Apparatus of the last Experiment*

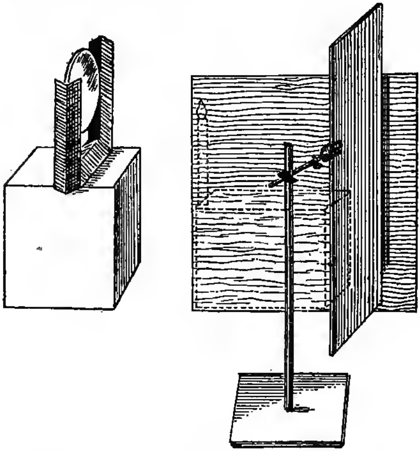
Hold a lighted candle in front of a plane mirror. From Exp. 10 we know that the image is as far behind the mirror as the object is in front. Place a sheet of paper parallel to the mirror at the place where the image should be. Do you see the image of the flame on the paper? If not, move the paper backward and forward to make sure that you have not missed it.

Images of self-luminous bodies that can be received on a screen are called *Real Images*; the rays of light which form the image actually pass through the spot where the image is seen. Those images that cannot be received on a screen are called *Virtual*; the rays of light do not pass through the spot where the image is seen, being stopped by the mirror, but if produced backwards behind the mirror they would pass through this spot. [The image of a pin or a needle cannot be received on a screen, even though it is real, because these objects are not self-luminous—*i.e.* do not emit light, but simply reflect it—so in testing if the image of an object is real or virtual use a flame instead of the object.]

Set up the apparatus of the last experiment, and place a lighted candle on the block (instead of the needle or pin) about 1 cm. or 2 cm. from the concave mirror.

Place a sheet of cardboard upright against the left side of the block on which the candle rests; but not projecting in front beyond the candle (see diagram). This shades one side from the light of the candle.

Turn the stand with a mirror round a few degrees to the side on which the cardboard is.



Hold a sheet of stiff paper or cardboard vertical and parallel to the mirror on the cardboard side of the candle, and move this paper backward and forward till (if possible) a *distinct* image of the flame is seen on the paper.

Fix the sheet of paper in a clamp stand, and measure the distance between the centre of the reflecting surface of the mirror and (1) the centre of the flame, (2) the image.

[If possible push the wick of the candle to the edge of the flame, and get the distinct image of the red end of the wick. This is the image of a point practically, and so the distances can be accurately measured with a straight-edge, a piece of thread, a pair of inside calipers, or a pair of dividers. Note that if you measure from the front side of the mirror you must add the thickness of the glass so as to get the distance from the *reflecting* side.]

If no image can be seen on the paper increase the distance of the candle from the mirror by 1 cm. and try again.

Repeat for distances increasing by 1 cm. or 2 cm., and arrange your results in a table.

Distance of Flame from Mirror	Is Image Real or Virtual?	If Real, what is Distance of Image from Mirror?	Is Image Inverted?	Is Image Larger or Smaller than Flame?

What is the use of the sheet of cardboard at the side of the candle? Why do you turn the mirror a little?

EXERCISE

Repeat the experiment with a convex mirror. Is the image formed by a convex mirror real or virtual?

EXPERIMENT **20**

To find the Radius of Curvature of a Concave Mirror

First Method

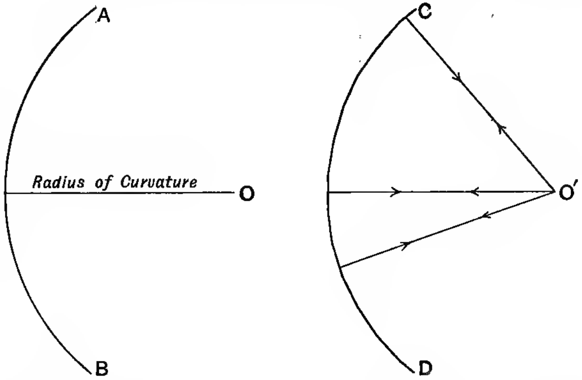
Apparatus—*Same as Exp.* 18

Arrange the apparatus as in Exp. 18, and by moving the needle backward or forward get it in such a position that the needle and the image always coincide. [Use the method of relative motion to find this position.]

Measure the distance between the point of the needle and the centre of the reflecting surface of the mirror. This distance is the radius of curvature.

Proof:

Let AB be a section of the mirror by a vertical plane. The mirror may be supposed to be made up of an innumerable number of minute plane mirrors at right angles to the radii of the sphere. AB will then have the appearance as shown by CD. If an object is placed at the centre O′, rays from the object will strike these mirrors normally, and so be again reflected to O′. Therefore when an object is placed at the *centre of curvature* the object and its image coincide.



[Note the difference between "centre of curvature" and "centre of reflecting surface" or "pole" of the mirror.]

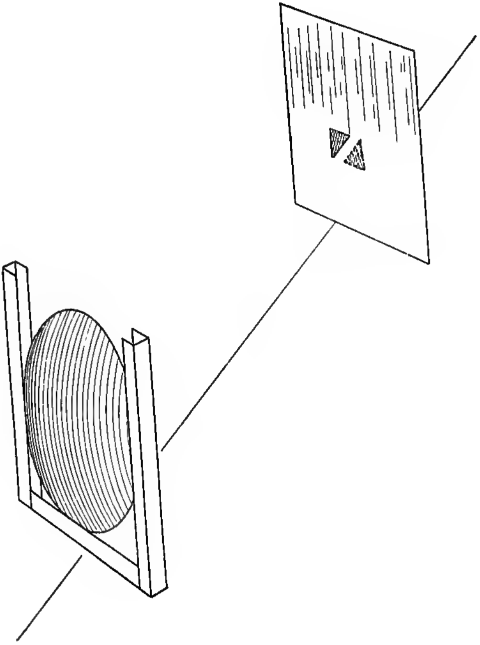
Second Method

Apparatus—*Sheets of stiff Paper*; *Wire Gauze*; *Candle or other Flame*; *Concave Mirror on Stand*; *Clamp Stand*; *Blocks of Wood*; *Gum*

Take two sheets of stout paper, and in the centre of each cut a triangular hole, each side being about 1·5 cm.

Cut a piece of gauze about 3 cm. square, and place it over the hole in one of the sheets. Gum the second sheet on the top of the first so that the two holes coincide, with the gauze between. This forms a screen, with an opening of wire gauze.

Set the mirror and candle on blocks a few centimetres apart, and clamp the screen vertically between them so that the flame, the centre of the gauze, and the centre of the mirror are on the same level.



Turn the stand with the mirror a few degrees to one side. Move the screen backward and forward till a distinct image of the gauze is shown on the screen. If the image on the screen is not near the gauze turn the mirror till the two just touch. Is the image erect or inverted?

Then as the object (the wire gauze) and its image are at the same distance from the mirror, and practically coincide, they are both at the centre of curvature.

Measure the distance between the gauze and the centre of the reflecting surface of the mirror. This distance is the radius of curvature.

Repeat several times, and take the average of the results.

Third Method

Apparatus—*Concave Mirror*; *Black Paper*; *Pen*

Cover the bright surface of the mirror with black paper, leaving a small circular hole (about 1 cm. diameter) at the centre.

Fasten a small piece of paper (less than 1 cm. long) to the end of a pen (between the pen points).

Hold the mirror so that the sun shines directly on it, and place the small piece of paper between the mirror and the sun.

Move the paper backward and forward till a small bright spot is seen on it.

Hold the paper steady where the spot is smallest and brightest, and ask your neighbour to measure the distance between the spot and the centre of the mirror.

This distance is called the *Focal Length*. The radius of curvature is double the focal length.

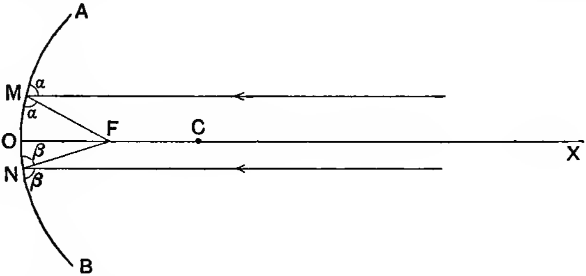
Proof:

Let AB be a section of the mirror with centre of curvature C. Let O be the centre of the reflecting surface. The line OX, which passes through C and O, is called the *Principal Axis*.

(Any other line passing through C and reaching the mirror is called a *secondary axis*. All secondary axes are normal to the mirror.)

AB, as before, may be supposed to be made up of small plane mirrors. The sun's rays come from such a distance that they may be taken as parallel.

Let a ray from the sun, travelling parallel to the principal axis, strike one of the small mirrors M. It is reflected according to the laws of reflection. By geometry it can be proved that, *if M is very near O* (in which case FO = FM approx.), the reflected ray will cut OC at a point F, midway between O



and C. (Prove this by joining MC. Then the alternate angles are equal. ∴ FC = FM = FO.) Similarly another parallel ray striking at N will pass through F, and so for all other parallel rays, therefore at F there will be a bright spot. F is called the *Principal Focus.*

If r = radius of curvature, and f = distance of focus from the centre of the reflecting surface (called the *Focal Length*), then $f = \frac{r}{2}$.

Exercise

Using the results of Exp. 18, find where an object must be placed from the focus or the centre of curvature of a concave mirror to give (1) a real image; (2) a virtual image.

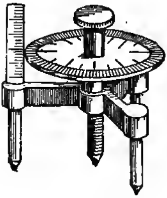
EXPERIMENT **21**

To use the Spherometer

Apparatus—*Spherometer*; *Glass Plate*; *Concave Mirror*

The Spherometer is an instrument on the same principle as the Micrometer Screw, and is used for finding the radius of a spherical mirror directly.

It consists of three vertical legs joined at the top by a cross-frame, the bottom points of the legs forming an equilateral triangle. In the centre of the cross-frame is a vertical screw in which a bolt works. Attached to the bolt is a horizontal graduated circle. A vertical scale is attached to the cross-frame. The pitch of the screw is generally ·1 cm. or ·05 cm.



The spherometer is placed on a level surface (*e.g.* a glass plate), and the bolt is turned till its point just touches the plate. If the bolt is turned too far the spherometer rocks when it is moved. Turn the bolt the opposite way till the rocking just stops. In this zero position the zero on the scale should be at or near the zero on the circle. Note the exact reading on the circle opposite the zero on the scale.

Place the spherometer so that the points of the three legs rest on the reflecting side of the mirror. Turn the bolt till its point just touches the mirror (test by rocking), and read off the distance that the bolt has moved vertically from the zero position.

Let d = vertical distance of the point of the bolt from its zero position,
a = average distance between the three legs,
r = radius of curvature of the mirror,

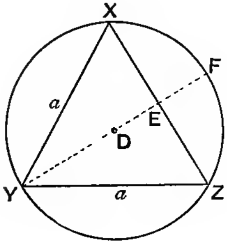
then by geometry it can be proved that $r = \frac{a^2}{6d} + \frac{d}{2}$.

Find by this formula the radius of curvature of the mirror used in the last experiment.

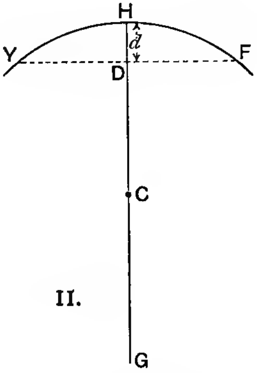
[The proof of the formula $r = \frac{a^2}{6d} + \frac{d}{2}$ is as follows:—

Let XYZ (Diagram I.) be the points of the three legs of the spherometer resting on the mirror. XYZ lie on a circle the diameter of which, YF, is a chord of the mirror. If XY $= a$, then the median YE $= \frac{a\sqrt{3}}{2}$, and since YD $= \frac{2}{3}$YE $\therefore$ YD $= \frac{2}{3} \times a\frac{\sqrt{3}}{2} = \frac{a}{\sqrt{3}}$.

Diagram II. shows a circular section of the mirror, C being the centre, r = radius, and GH a diameter. Then GD·DH = YD·DF (rectangles contained by segments of chords of a circle are equal).



I.



II.

$$\therefore (2r-d)\,d = \frac{a}{\sqrt{3}} \times \frac{a}{\sqrt{3}}. \quad \therefore 2rd - d^2 = \frac{a^2}{3}. \quad \therefore r = \frac{a^2}{6d} + \frac{d}{2}.\Big]$$

EXPERIMENT **22**

To find a Relation between the Distance of an Object and the Distance of its Image from a Concave Mirror

First Method

Apparatus—*Same as Exp.* 18; *Needle on Block*

Arrange the apparatus as in Exp. 18, the top of the needle or pin being on the principal axis of the mirror about 1 or

2 cm. away. Move the pin about half-a-centimetre to one side of the axis. Test if the object or its image is nearer you.

Place another long needle or pin on a block in front of the mirror, and move it about till it always coincides with the image of the first needle. If you cannot manage this with the second needle in front of the mirror, try if the image is behind the mirror.

When the position of the image has been found, measure (1) the distance between the object and the mirror; (2) the distance between the image and the mirror.

Remove the object back a little from the mirror, and repeat. Do this for several positions of the object, and arrange your answers in a table.

I.	II.	III.
Distance of Object from Mirror (u)	Distance of Image from Mirror (v)	$\frac{1}{u}+\frac{1}{v}$

In finding the distances u and v you will notice that sometimes the image is in front of the mirror and sometimes behind it. To distinguish the two positions the following convention is used :—

All distances measured from the mirror in the direction of the object (e.g. *a flame*) *are called* positive; *all distances measured in the opposite direction are called* negative.

Place the right sign before the distances in Columns I. and

II. of the table, and then find the answers in Column III. Arrange the answers in Column III. as fractions, with 1 as the numerator—*e.g.* if the answer is $\frac{2}{9}$, put it as $\frac{1}{\frac{9}{2}}=\frac{1}{4\frac{1}{2}}$.

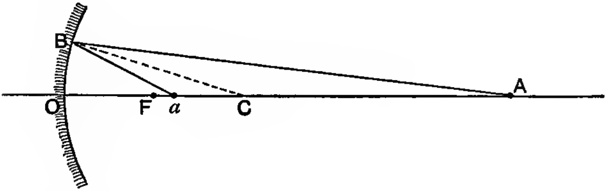
What do you notice about the sign and the magnitude of the answers in Column III.?

Find the radius of curvature of the mirror by one of the methods of Exp. 20. What is the focal length of the mirror?

Is there any relation between the answers in the third column and the focal length of the mirror? Can you write the formula, connecting the results? Given that $f=\frac{r}{2}$, write the formula connecting u, v, and r.

Note.—The formula $\frac{1}{u}+\frac{1}{v}=\frac{2}{r}$ can be proved geometrically.

Let AB be a ray from A striking the mirror near the axis OA. The ray is reflected along Ba so that $\angle a\text{BC} = \angle \text{ABC}$ (why?). Then $\text{AO}=u$; $a\text{O}=v$.



If BO *is small compared with* BA, AB = AO (approx.), and aB = aO (approx.).

By geometry, since BC bisects $\angle \text{AB}a$,

$$\frac{\text{AB}}{a\text{B}}=\frac{\text{AC}}{a\text{C}} \qquad \therefore \qquad \frac{\text{AB}}{a\text{B}}=\frac{\text{OA}-\text{OC}}{\text{OC}-\text{O}a}.$$

$$\therefore \frac{u}{v}=\frac{u-r}{r-v}. \qquad \therefore ur-uv=uv-vr.$$

$$\therefore r(u+v)=2uv. \qquad \therefore \frac{1}{u}+\frac{1}{v}=\frac{2}{r}.$$

Second Method

Apparatus—*Same as Exp.* 19

Fit up the apparatus of Exp. 19, move the sheet of paper till a distinct image of the flame is seen, and measure the distance of the object and of the image from the mirror.

Arrange your answers in a table as before.

Note.—If you have filled up the table of Exp. 19 you do not require to do this experiment, as the figures in Column I. $= u$ and those in Column III. $= v$.

EXERCISES

1. Using the formula found above $\left(\frac{1}{u}+\frac{1}{v}=\frac{2}{r}\right)$, find the radius of curvature of a concave mirror.

2. What is the value of u and of $\frac{1}{u}$ when the object is the sun? Compare the values of v and f in this case. Where will the image be? (See Exp. 20, Third Method.)

3. When the object is placed at the centre of curvature of the mirror, what is the value of v? Where will the image be? (See Exp. 20.)

4. Draw a graph of the corresponding values of u and v in Columns I. and II., also a graph of the corresponding values of $\frac{1}{u}$ and $\frac{1}{v}$.

5. In a plane mirror the reflecting surface may be taken as a part of a circle with infinite radius, therefore f is infinite. Find from the formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ where the image in a plane mirror should be.

6. Using the formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, find when the image in a concave mirror is behind or in front of the mirror (*i.e.* is virtual or real).

7. Fit up the apparatus of the second method, and get a distinct image of the candle flame on the screen. Measure

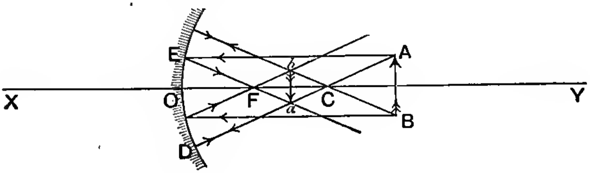
the distances u and v. Now interchange the candle and the screen so that the candle is at a distance v and the screen at a distance u from the mirror. Do you see an image on the screen? These interchangeable positions of the object and the image are called *Conjugate Foci.* How many pairs of conjugate foci can there be?

EXPERIMENT **23**

To find, by Drawing, the Nature and Position of the Image in a Concave Mirror

Apparatus—*Sheet of Paper*; *Straight-edge*; *Compasses*

Draw a line XY to represent the axis of the mirror. With centre (C) on this line, draw an arc of any radius (say 4 cm.)



to represent the mirror. Let this arc cut XY in O. Bisect OC at F. F is the principal focus.

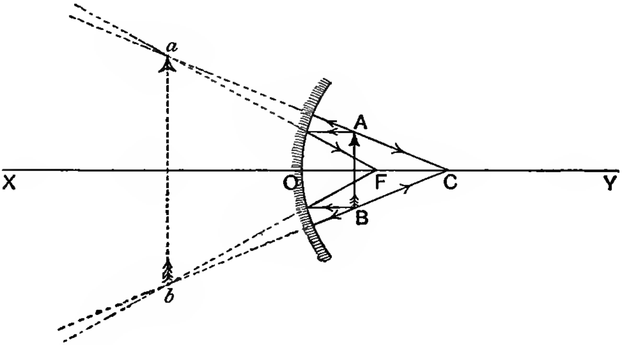
An object on the principal axis may have one of six positions:—(1) at an infinite distance; (2) at a finite distance beyond the centre of curvature; (3) at the centre of curvature; (4) between the centre of curvature and the focus; (5) at the focus; (6) between the focus and the mirror.

Draw an arrow beyond C to represent an object in position (2). From A rays reach the mirror in all directions. One ray AD will pass through the centre of curvature C. This ray will reach the mirror normally, and therefore will be reflected back along the path DA. Therefore the image of A must lie somewhere along the line DA.

Another ray AE from A will travel parallel to the principal axis OY, and as such parallel rays pass through the principal focus F, it follows that the image of A lies somewhere along the line EF. Therefore the image of A is at the intersection of AD and EF.

In the same way find the position of the image of B. Note the position and size of the image.

Make drawings for the other four positions of the object (the drawing for the sixth position is given).



Answer the following:—When is the image in a concave mirror (1) real; (2) imaginary or virtual; (3) erect; (4) inverted; (5) enlarged; (6) diminished; (7) enlarged and imaginary?

What peculiarity do you notice about the drawing when the object is at the principal focus? Can you give any reason why no image is formed? When the object is at an infinite distance (*e.g.* the sun) where is the image?

The following table shows the results which should have been obtained:—

Position of Object	Position of Image	Nature of Image
I. At an Infinite Distance.	At Focus.	Real, Inverted, Diminished.
II. Beyond Centre of Curvature.	Between Centre of Curvature and Focus.	Real, Inverted, Diminished.
III. At Centre of Curvature.	At Centre of Curvature.	Real, Inverted, equal to Object.
IV. Between Centre of Curvature and Focus.	Beyond Centre of Curvature.	Real, Inverted, Enlarged.
V. At Focus.	At an Infinite Distance.	———
VI. Between Focus and Mirror.	Behind the Mirror.	Imaginary, Erect, Enlarged.

EXERCISES

1. A concave mirror has a focal length of 10 cm. An object is set (i.) 5 cm., (ii.) 10 cm., (iii.) 20 cm. in front of it. Where is the image in each case?

2. An object is set 4 cm. in front of a concave mirror 9 cm. focal length. Is the image in front of or behind the mirror?

3. A man standing 1 foot in front of a mirror sees his image 16 inches behind the mirror. Is the mirror plane? If not, what is the radius of curvature?

4. An object 10 cm. in front of a mirror has an image 10 cm. behind the mirror. What is the focal length of the mirror?

EXPERIMENT **24**

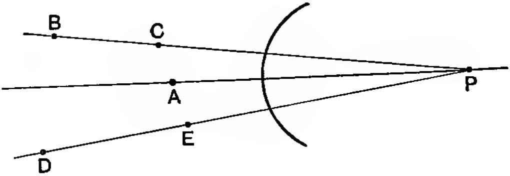
To find the Radius of Curvature of a Convex Mirror

Apparatus—*Convex Mirror with Stand*; *Blocks*; *Pins or Needles*; *Candle*

First Method

Place the mirror on a block, and set a candle in front of it. Try to get an image of the flame on a paper screen as in Exp. 19. Do you succeed in any position of the candle? Is the image real or virtual?

Instead of the candle place in front of the mirror a pin or a needle stuck upright in another block so that the top of the needle is on a level with the principal axis of the mirror.



Place the object as near to the mirror as possible. Notice the size of the image and if it is upright or inverted. Gradually move the object from the mirror, and note any changes in the image.

Set the object (A) a few cm. in front of the mirror. Stick other four pins (or needles) in blocks about the same height as A.

Place two of these (B and C) to the left of A so that B, C, and the *image* of A appear in a straight line.

Do the same with the other two pins D and E on the right of A.

Then the intersection of the the lines BC and DE will mark the position of the image of A.

Place a tall needle P on a block (the top of P being higher than the top of the mirror), and set P behind the mirror.

Look along the line BC, and place P so that B, C, and P are in a straight line.

Look along the line DE, and if P is not in a straight line move it till it is.

By the method of relative motion find if P always coincides with the image of A. If not, move P slightly till the two coincide.

Measure the distance (u) between the object A and the centre of the reflecting surface of the mirror and the distance (v) of the image from the mirror, and find the value of $\frac{1}{u}+\frac{1}{v}$, and so find the radius of curvature. (Note the signs of u and v.)

What do you notice about the sign of r? What does this mean?

Repeat with the object A at various distances from the mirror, and arrange your results in a table.

Second Method

Scrape the silver off a strip of the mirror from the outside edge to within ·5 cm. of the centre. The strip if produced should pass through the centre of the mirror Make the strip 2 or 3 mm. broad. [The silver can be easily removed by dipping a glass rod in acid and rubbing it along the strip.]

Place the mirror on the stand so that the strip is vertical, and on the upper side, and set the stand on a block.

Stick a needle upright on a block, and place it in front of the mirror, and arrange so that the image of the needle (or part of it) is in a line with the strip. Set another needle on a block behind the mirror so that this needle can be seen through the mirror.

By the method of relative motion find whether the second needle or the image of the first needle is farther behind the mirror.

Move the needle which is behind the mirror till it always coincides with the image. Then it marks the position of the image.

Measure u and v, and so find the radius of curvature.

EXERCISES

1. Find the radius of curvature of the mirror used in the experiment by the spherometer (see Exp. 21).

2. What is the position of the image of an object placed (1) 2 cm., (2) 20 cm. in front of a convex mirror of 10 cm. focal length?

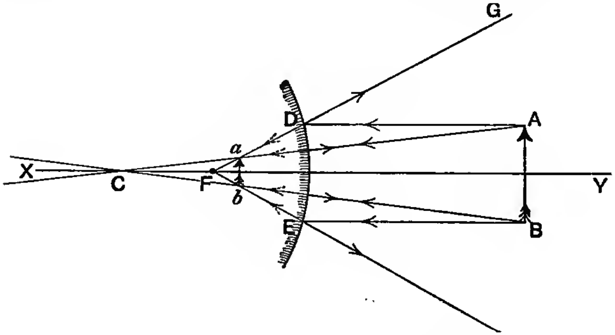
3. A pin is set 25 cm. in front of a mirror and the image is found to be 5 cm. behind the mirror. What kind of mirror is it? What is the focal length?

EXPERIMENT **25**

To find, by Drawing, the Nature and Position of the Image in a Convex Mirror

Apparatus—*Sheet of Paper*; *Straight-edge*; *Compasses*

Draw a line XY to represent the principal axis, and a curve to represent the mirror with centre of curvature C, and focus F (where F is a *virtual* focus, for, of course, the rays cannot pass through the mirror). Draw an arrow AB any distance greater than $2f$ in front of the mirror.



Draw from A two rays to the mirror, one normal passing through C, and the other parallel to the principal axis, and reflected along DG in a line with DF. The image of A is at the intersection of AC and DG. (Why?)

Similarly find the image of B.

Is the image of AB real or virtual, erect or inverted, enlarged or diminished?

Make a drawing for the positions of the image when the object is at a distance (1) between 2 f and f; (2) less than f from the mirror. Describe the image.

EXPERIMENT **26**

To find a Relation between the Size of an Object and of its Image in a Concave Mirror [Magnifying Power of a Mirror]

Apparatus—*Paper Screen with hole filled with Wire Gauze (used in Exp.* 20); *Stiff Sheet of Millimetre (squared) Paper set vertically in Clamp Stand*; *Concave Mirror in Stand*; *Candle or other Flame*; *Blocks of Wood*

Measure carefully in millimetres the height of (say) 10 meshes of the wire gauze.

Place the mirror, wire gauze, and flame in a line on the same level, the gauze being a few cm. from the mirror and parallel to it.

Turn the stand with the mirror a little to one side. Place the millimetre paper in front of the gauze screen (but not covering the gauze itself), and move the millimetre paper backward and forward till a distinct image of the gauze is seen on the paper. [If you cannot get a distinct image move the gauze farther back from the mirror and try again.]

When the image is as distinct as possible clamp the millimetre paper, count 10 meshes on the image, and read their height on the millimetre paper. This gives the height of the image.

Measure the distance between the mirror and the object and between the mirror and the image.

Repeat with the gauze at various distances from the mirror.

Arrange your results in a table.

Distance of Object from Mirror	Distance of Image from Mirror	Height of Object	Height of Image	$\frac{\text{Distance of Object}}{\text{Distance of Image}}$	$\frac{\text{Height of Object}}{\text{Height of Image}}$

What do you notice about the corresponding results in the last two columns?

Note.—*Size* here means length or breadth or height but not area.

EXERCISES

1. In the experiment the object is always farther away from the mirror than the image is. Replace the gauze screen by a small piece of gauze (say 1 square inch) held vertically in a clamp stand, and place the gauze very near the mirror, so that the image will be received on a screen behind the gauze. Measure the heights and distances as in the experiment, and find if the same relation holds.

2. An object 3 cm. high is placed (i.) 3 cm., (ii.) 12 cm., (iii.) 18 cm., (iv.) 27 cm. in front of a concave mirror, the radius of curvature of which is 18 cm. Find the position and size of the image in each case. State if the image is erect or inverted, and real or virtual.

3. A pin 4 cm. high is placed 8 cm. in front of a concave mirror. The real image is 12 cm. high. Find the position of

the image and the radius of curvature of the mirror. Find the answers when the image is virtual.

4. A concave reflector is set 6 inches behind a flame, and an image of the flame is seen on a wall 4 feet away. Find how many times the image is as large as the flame (*i.e.* the *magnification*), and find the focal length of the reflector.

5. A concave mirror has a radius 10 cm. How far from the mirror must a pin be placed so that the magnification of the image may be 5? [Here $v = 5u$ (why?).]

EXPERIMENT **27**

To find, by Drawing, the Relation between the size of an Object and of its Image in a Concave Mirror

Apparatus—*Same as Exp.* 23

Construct the drawings as in Exp. 23, and measure the heights of the object and image and the corresponding distance from the mirror. Find if there is any connection between the fractions

$$\frac{\text{Distance of Object}}{\text{Distance of Image}} \text{ and } \frac{\text{Height of Object}}{\text{Height of Image}}.$$

EXERCISES

1. A pin 3 cm. high is placed 10 cm. in front of a concave mirror having focal length of 15 cm. How high is the image?

2. An object 25 cm. high and placed 10 cm. in front of a concave mirror has an image 10 cm. high. What is the focal length of the mirror?

EXPERIMENT **28**

To find, by Drawing, the Relation between the size of an Object and of its Image in a Convex Mirror

Apparatus—*Same as Exp.* 25

Construct the drawings as in Exp. 25, and measure the height and the distance of the object and its image. Repeat with other positions of the object, and find if the relation between the fractions

$$\frac{\text{Distance of Object}}{\text{Distance of Image}} \text{ and } \frac{\text{Height of Object}}{\text{Height of Image}} \text{ is always the same.}$$

EXERCISES

1. An object 6 cm. high is placed 10 cm. in front of a convex mirror whose focal length is 20 cm. What is the position and size of the image?

2. An object is placed in front of a convex mirror at a distance equal to its focal length. What is the position and the size of the image?

EXPERIMENT **29**

Reflection from a large Curved Surface

Apparatus—*Concave and Convex Cylindrical Mirrors*;[1] *Sheet of Paper*; *Pins*

Pin a sheet of paper on the bench, and place the concave mirror vertically on it. Mark its position by drawing on the paper a line along its concave surface.

Place a pin A on the principal axis about 1″ or 2″ in front of the concave surface. Look past A nearly normally into the mirror, and place two pins B_1 and C_1 in front of the mirror so that B_1, C_1, and the *image* of A are in a straight line. Mark the position of the pins B_1, C_1, and remove them.

Again look past A into the mirror, but not so near the normal (on the left side), and place other two pins B_2, C_2 in a straight line with the image of A.

Proceed in the same way for other positions, turning more and more from the normal, and inserting two pins each time.

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[1] The mirror may be made of a strip of polished or nickel-plated metal (say 8″ × 1″) bent to form a semi-cylinder. The outer surface forms a convex mirror, the inner surface a concave mirror. [Good results are got by using a metal alarum clock or a copper calorimeter as a convex mirror.]

Remove the mirror, and draw lines through the position of the pins B_1C_1 and B_2C_2. Then the point where these two lines intersect marks the position of an image of A. (Why?) Call this image A_1.

Similarly the intersection of the lines B_1C_1 and B_3C_3 also marks the position of an image of A. Do these lines intersect at A_1? If not, call their point of intersection A_2, and proceed with the lines B_2C_2 and B_3C_3, etc.

Repeat with pins b_1, c_1; b_2, c_2; etc., on the right side of the normal.

You will find that different images of A are produced. The rays which are nearly normal intersect at the point A_1, but those rays which are not nearly normal intersect at different points.

Thus if the pin A had been a flame we would have a series of bright images A_1, A_2, A_3, etc., instead of one bright image A_1. These images form a curve which is called a *Caustic*. Draw the caustic through the points A_1, A_2, etc., on the paper. The inability of a mirror to collect to one focus all the rays falling on it is called *aberration*.

Repeat with a convex mirror.

EXERCISES

1. Take the bent strip of metal used in the experiment and place it vertically on a sheet of white paper. Place a lighted candle in front of the concave surface so that the flame is a little above the level of the strip, and notice the shape of the caustics on the paper.

2. Fill a tumbler with milk and place in bright sunlight (gaslight will often do). What do you see on the surface of the liquid? What is its shape? What is the cause of its appearance?

3. Place a flame in front of a large metallic concave mirror (*e.g.* the reflector of a lamp). Slightly tilt the mirror forward so that the rays are reflected downward. Place a sheet of paper horizontally in front of the mirror (near the bottom), and move it about till a caustic is seen on it. What is its shape?

4. Give the reason why in Exp. 20 (Third Method)

you covered the bright surface of the mirror, except a small portion near the principal axis.

5. Why do you see a distorted image of your face when you look at a bright spoon or at the polished strip of metal used in the experiment?

EXAMINATION PAPER (Exp. 18-29)

1. Describe the changes in the position, size, and shape of the image of a pin placed in front of a concave mirror, as the pin is gradually moved back from the mirror.

2. What is meant by *Real* and by *Virtual* images? What kind of image is produced (1) in a concave mirror; (2) in a convex mirror?

3. Define Radius of Curvature, Principal Focus, Principal Axis, Centre of Mirror, Centre of Curvature, illustrating with a diagram.

4. Describe one method of finding the radius of curvature of a concave mirror.

5. A pin 3 cm. high is placed 8 cm. in front of a concave mirror (radius of curvature 5 cm.). Where is the image?

6. What is meant by magnification of an image? What is the size of the image in Question 5?

7. State the rule of signs in measuring distances from mirrors. In the formula $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$ state what is meant by each letter. What is the sign of each when the mirror is convex?

8. A point of light is 50 cm. in front of a mirror and the image is 10 cm. in front of the mirror. What is the focal length of the mirror? Is the mirror convex or concave?

9. Can you get a real image of the sun by a concave mirror? If so, where is the image formed? What is the direction of the rays?

10. A mirror is silvered on the front and so cannot be touched with the fingers. How would you find out whether the mirror is plane, concave, or convex?

11. What is a caustic? How is it formed? How would you trace the caustic formed by a large polished cylinder?

CHAPTER V

REFRACTION AT PLANE SURFACES

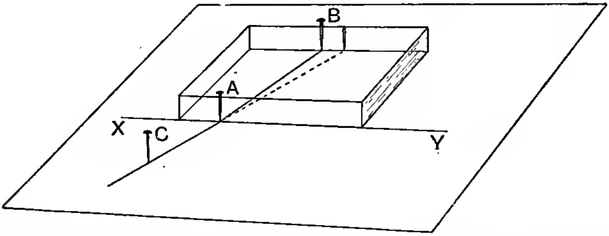
EXPERIMENT 30

To study the Laws of Refraction at a Plane Surface

Apparatus—*Rectangular Glass Slab* (*say* 10 *cm.* × 5 *cm.* × 1·5 *cm.*) ; *Paper* ; *Pins* ; *Protractor* ; *Table of Sines*

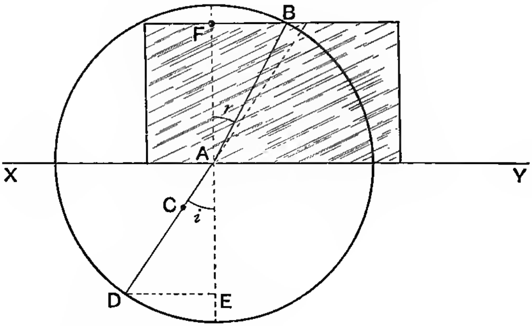
PIN a sheet of paper on the bench, and draw a line XY across the paper. Place the glass slab so that one long narrow surface is vertically over XY.

Stick a pin A upright on XY near one corner of the slab, and touching the slab, and another pin B against the opposite surface of the slab, and near the middle of the surface (*i.e.* the line AB runs obliquely across the slab).



Look past A *through the slab* at B, and place a third upright pin C in front of the slab, close to XY, so that C, A, and B appear in a straight line. [Note that B must be viewed through the slab and not above it. To ensure this, cover the top of B with a sheet of paper or a block of wood.]

Draw a line on the paper round the perimeter of the slab, and remove the slab. Join BA and CA. Are C, A, and B in a straight line? What has happened to the ray CA when it passed into the glass slab? The ray CA is said to be *refracted* at the plane surface over XY where the atmosphere and the slab meet. Similarly if BA is a ray passing from the slab to the air it is refracted when it emerges from the glass into the air.



Through A draw a normal FAE to XY. The angle CAE is called the *Angle of Incidence* (i) of the ray CA, and the angle BAF the *Angle of Refraction* (r).

Measure the angles i and r. Find Sine i and Sine r from trigonometric tables of sines,[1] and so get the ratio $\frac{\text{Sine } i}{\text{Sine } r}$.

[Those who have not studied trigonometry may proceed thus:

With A as centre, and any radius (say AB), cut the line AB in B and the line AC in D. From B and D draw BF and DE perpendicular to FAE.

Then the fraction $\frac{DE}{AD}$ is called Sine ∠ DAE—*i.e.* Sine i—and the fraction $\frac{BF}{AB}$ is called Sine ∠ BAF—*i.e.* Sine r.

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[1] See Table of Sines at the end of this book.

$$\therefore \frac{\text{Sine } i}{\text{Sine } r} = \frac{\frac{\text{DE}}{\text{AD}}}{\frac{\text{BF}}{\text{AB}}} = \frac{\text{DE}}{\text{BF}} \text{ (since AD} = \text{AB).}$$

Measure DE and BF, and so get $\frac{\text{DE}}{\text{BF}}$.]

The fraction $\frac{\text{Sine } i}{\text{Sine } r}$ is called the *Index of Refraction* of light which passes from one medium into another, and is written ${}_a\mu_b$ where a is the medium in which the incident ray travels, and b the medium in which the refracted ray travels.

Repeat the experiment, with A and B in different positions, and arrange your results in a table.

Angle of Incidence (i)	Angle of Refraction (r)	Sine i	Sine r	$\mu = \frac{\text{Sine } i}{\text{Sine } r}$

Is the index of refraction of light constant when it passes from air into glass?

When light passes from air into glass, is the angle of refraction greater than, equal to, or less than the angle of incidence? In other words, is the ray bent towards or away from the normal to the surface?

The *Laws of Refraction* are:

(1) When a ray of light passes obliquely[1] from one body

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[1] See Ex. 1.

(called a *medium*) to another it is turned from its original path in such a way that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for the same two media.

(2) The incident ray, the normal, and the refracted ray are in the same plane.

Note.—It is found that a ray on passing from one medium into a denser medium is refracted *towards the normal*; on passing from a dense medium into a rarer medium it is refracted *from the normal.*

EXERCISES

1. Repeat the experiment, placing BA on a normal to XY, and C so that C, A, and B appear to be in a straight line. Remove the slab, and find if the ray CA has been turned from its path.

2. Find the index of refraction from glass to air. What relation has it to the index of refraction from air to glass? [In the former case the incident ray is BA and the refracted ray AC.]

3. Place a stick or a straight-edge obliquely into a trough of water, and look at it sideways (*i.e.* the stick appears shortened.) What do you notice about the stick? What are the two media in which the stick is? Explain (by a diagram) why the stick appears bent at the surface of the water.

4. Make a large blot on a sheet of paper, and place a glass slab so that a vertical surface is over the middle of the blot—*i.e.* a part of the blot is under the slab. Look obliquely at the blot from the same side of the slab. Part of the blot is seen through the slab and part outside the slab. What do you notice about the relative positions of the two parts of the blot?

5. In the bottom of an opaque trough or sink place a coin. Move back from the trough till the coin just disappears from sight. Keep your eye steady while your neighbour pours water into the trough. What happens to the coin as the water rises in the trough? Explain by a diagram.

6. Why is a metallic mirror or a glass slab with darkened back better than a glass mirror with silvered back, for experiments in reflection?

7. Look above an ordinary gas or bunsen flame. A wavy

or quivering motion is noticed. This is due to irregular refraction of light by the heated air which is ascending since it is less dense than the cold air.

EXPERIMENT **31**

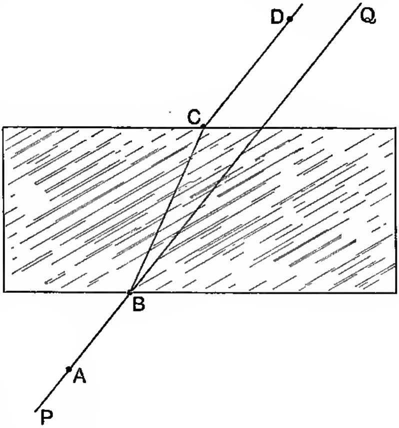
To find the Effect of placing a Slab of Glass across the Path of a Ray of Light

Apparatus—*Slab of Glass*; *Sheet of Paper*; *Pins*; *Protractor*

Pin a sheet of paper on the bench, and on it draw a line PQ to mark the path of a ray of light. On the line place two pins A and B upright and a few centimetres apart.

Place the slab obliquely across the line PQ, touching the pin B (see diagram).

Look along AB through the slab, and place a pin C against the opposite surface of the slab so that A, B, and C (when seen through the slab) appear to be in a straight line.



Place a fourth pin D beyond the slab so that A, B, and C, D (when seen through the slab) appear to be in a straight line.

Remove the slab. Join BC, CD. The original path of the light is along PQ. The new path is along ABCD. CD is called the *Emergent Ray*.

When the ray enters the slab at B it is turned from its first path. The angle (QBC) through which it is turned is called the *Angle of Deviation*.

Measure the angle between the incident ray AB and the emergent ray CD. Are the two rays parallel?

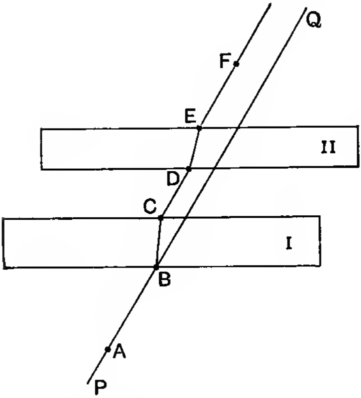
The ray AB after its passage through the slab proceeds in the same direction as before, since CD is parallel to AB (but not in the same line as before). Does the slab cause a ray to deviate from its original direction? What is the effect of the slab on the ray?

Exercises

1. A person looks through a window at an object. Does he always see the object in its exact position? Hold a sheet of plane glass vertically between your eye and a distant object (say a tree or a pole). Keeping your eye steady, raise the glass so that you may see the top part of the tree or the pole through the glass and the bottom part directly. Are the two parts in a line?

2. Place a sheet of glass on a page with ruled lines (*e.g.* your note-book). Look at the lines through the glass (1) normally; (2) obliquely. Is there any difference in the position of the lines at the edges of the sheet of glass?

3. Find the effect of placing two slabs of glass in the path of a ray of light. Repeat the experiment (placing the slab with a narrow surface on the paper), and trace the path of the ray through the Slab I. by the pins A, B, C, D. Place a second slab against D and parallel to the first slab. By pins E, F trace the path of the ray through it—*i.e.* A, B, C, D, E, F appear in a straight line when the eye is at P. Remove the slabs, and by drawing the path, find if there has been any deviation.



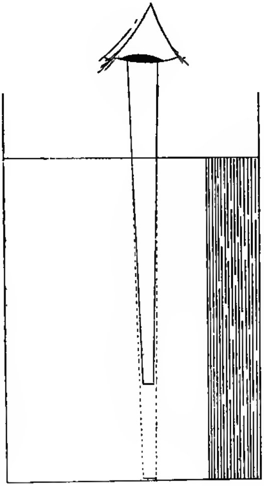
4. Find the effect of placing *different* media in the path of

a ray of light. Procure a rectangular glass trough, and fill it full of water. Then you have two slabs of glass and one slab of water. Trace by means of pins the path of a ray through the glass and the water, and find if the ray suffers any deviation when it emerges from the glass.

5. If the trough used in Ex. 4 has parallel sides it may be used to find the approximate refractive index of liquids in the same way as Exp. 30, as the rays suffer no deviation from the glass. Fill the trough with (1) water, (2) turpentine, (3) carbon bisulphide, and by tracing the path of a ray with pins, find the refractive index of each liquid.

6. Place a pin or a flame in front of a glass slab. Do you see an image? Are all the rays of light which strike the surface of the slab refracted through it? If not, what happens to some of them? A number of glass plates (*e.g.* microscope slides) are placed in a pile one on top of another. Why is it that you cannot see clearly an object under the pile? (No body is perfectly transparent. Thus clouds, which consist of small transparent drops of water, appear black underneath because the most of the sun's rays are reflected back from them. What appearance would clouds have if they were viewed from above? Similarly if transparent glass be powdered it appears white because the rays of light are reflected from the particles. It is because of this that the deep sea appears almost black.)

7. Prove that if two parallel rays pass through a rectangular glass slab they will emerge parallel.



8. Place a coin in the bottom of a tall jar, and put the jar on the bench. On the bench beside the jar place a pile of coins so that the top coin is at the same level as the coin in the jar. Look straight down at the coins, one eye being over the coin in the jar and the other eye over the coin outside. Get your neighbour to fill the jar slowly and gently with water.

What do you notice about the position of the coin in the water? Can you give the reason? (See diagram and Exp. 32.)

9. Why does a pool or a swimming pond full of water appear shallower than it really is?

10. A small air bubble is exactly at the centre of a glass ball. What is its apparent position to a person looking at the ball?

11. What is the angle of deviation of a ray which is reflected from a plane mirror (in terms of the angle of incidence). Find the duration when (1) the angle of incidence is 45°; (2) the angle between the incident and reflected rays is 70°; (3) the incident ray is normal to the mirror.

EXPERIMENT **32**

To find the Index of Refraction of a Liquid

Apparatus—*Deep Glass Jar or Can*; *Small Piece of bright Metal Foil*; *Long Polished Needle*; *Clamp Stand*; *Steel Straight-edge*

Place the can upright on the bench, cut a narrow strip of the foil about 20 mm. × 2 mm., and place it in the bottom of the can.

Pour water into the can to the depth of (say) 15 or 20 centimetres. Measure with a steel straight-edge the distance between the foil and the surface of the water (say a cm.).

Clamp the polished needle horizontally in a stand so that the needle is exactly over the metal strip and parallel to it. Look *vertically* down past the needle into the water. An image of the needle is seen as far below the surface as the needle is above it (since the water is a plane mirror).

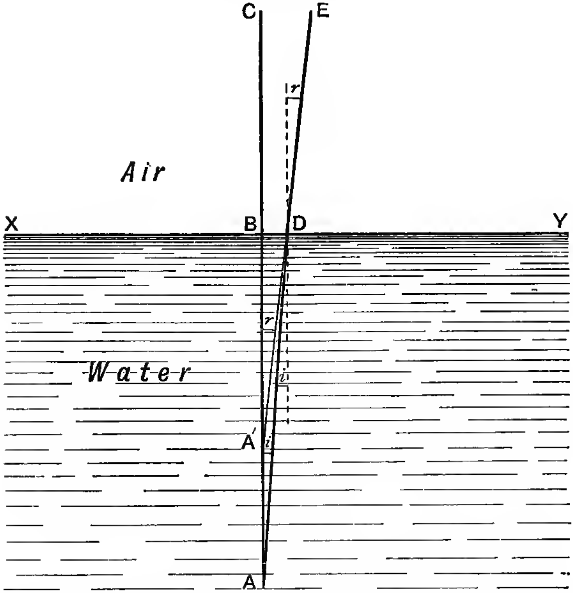
By moving the head a little to one side find (by the method of relative motion) whether the image of the needle or the foil as seen by refraction through the water is the nearer. Move the needle slowly up or down in the clamp till the two images exactly coincide.

Measure the perpendicular distance between the needle and the surface of the water (say b cm.). This is the apparent depth of the foil below the surface of the water.

Then the Index of Refraction from air into water $= \frac{a}{b}$.

Proof:

Let XY be the surface of the water. Let A be a point of the foil from which a small pencil of rays proceeds to the eye.



Let ABC be a normal ray (which is not refracted at the surface of the liquid) and ADE another ray which is refracted at D. If i = angle of incidence and r = angle of refraction, both must be very small since the pencil of rays is supposed to enter an eye looking vertically down.

If μ_1 = Index of Refraction from *water* to *air*,

$$\mu_1 = \frac{\text{Sine } i}{\text{Sine } r} = \frac{\frac{\text{BD}}{\text{DA}}}{\frac{\text{BD}}{\text{DA}'}} = \frac{\text{DA}'}{\text{DA}}.$$

But as the angles i and r are very small, DA = BA (approx.), and DA′ = BA′ (approx.).

$$\therefore\ \mu_1 = \frac{BA'}{BA}.$$

$$\therefore\ \text{Index of Refraction from } \textit{air} \text{ to } \textit{water} = \frac{1}{\mu_1} = \mu = \frac{BA}{BA'}.$$

$$\therefore\ \mu = \frac{\text{Actual depth below surface}}{\text{Apparent depth below surface}}.$$

Note.—This relation is true only when a person looks normally down at the body in the water. When the rays are oblique, DA is not equal to BA.

EXERCISES

1. Repeat the experiment with other liquids—*e.g.* alcohol, turpentine, etc.

2. A fish appears to be 6 inches under the surface of water. What is the real depth? (Index of refraction from air to water $= \frac{4}{3}$.)

3. A dish of liquid appears to be 12 inches deep. The real depth is 15 inches. What is the index of refraction?

4. In the centre of a slab of glass (index of refraction = 1·5) is an air hole. It is situated 3 cm. below the top of the slab. What is its apparent position to an observer looking vertically down at it?

5. A slab of glass 6 cm. thick (index of refraction 1·5) is placed between the eye and an object. What difference will there be in the apparent distance of the object from the eye?

EXPERIMENT **33**

To trace the Path of a Ray through a Prism

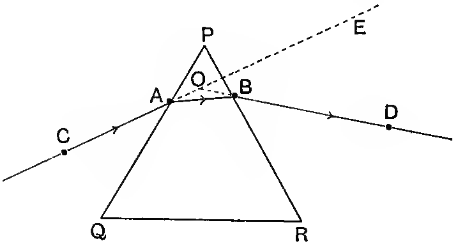
Apparatus—*Triangular Glass Prism*; *Sheet of Paper*; *Pins*; *Protractor*

Pin the sheet of paper on the bench. Place the prism upright on the paper, and draw a fine line on the paper round its triangular base PQR.

Near P (say 1 cm. distance) stick two pins A, B upright, and touching the prism—A on the line PQ and B on the line PR.

Look horizontally (close one eye) through the prism from the side PQ, and move your head till A covers B. Then stick a pin C between the prism and your eye so that C, A, B appear in a straight line.

Look through the prism from the side PR so that B, A, C appear in a straight line, and stick a pin D between the prism and your eye so that D, B, A, C appear in a straight line.



Look through the prism along CA. Do C, A, B, D appear in a straight line? Then CABD is the path of a ray of light.

Remove the prism. Join CA, and produce the line. Join AB and BD, and produce DB to meet CA at O. Are C, A, B, D in a straight line? What has happened to the ray at A and B?

If the prism had not been placed in the path of the ray, the ray would have travelled in the line CAE. Since it now travels along BD it has been turned or deviated through the angle EOD. This angle is called the *Angle of Deviation.*

Measure the angle of deviation EOD, the angle of incidence (angle between the incident ray and the normal—*i.e.* 90° − ∠ CAQ), and the angle of emergence (90° − ∠ DBR).

Trace other rays through the prism, and measure the angles. Arrange your answers in a table.

I. Angle of Incidence 90° – ∠CAQ	II. Angle of Emergence 90° – ∠DBR	III. Difference between I. and II.	IV. Angle of Deviation

Can you see any connection between the answers in Columns III. and IV.?

Arrange the pins so that the angle of incidence is equal to the angle of emergence. This is done by placing the pins A and B exactly the same distance from P. Measure the angle of deviation in this case. Is the angle larger or smaller than any of the angles in Column IV.? When the angles of incidence and emergence are equal, the deviation of the ray is less than for any other position of the prism, and the ray is said to have a path of *Minimum Deviation.*

EXERCISES

1. You will notice that the ray CA both on entering and emerging from the prism is refracted from the edge P of the prism. Why is this? [See Note on Index of Refraction, Exp. 30.] The vertical edge above P is called the *Refracting* edge and the angle at P the Refracting angle. The result is that a person looking through the prism along the line CA sees the pin D along the line CAE—*i.e.* D appears nearer the edge P than it really is. In other words, objects when seen through a prism appear deflected towards its summit or refracting edge. Hold a prism vertically between your eye and a flame, the summit to the left hand and the prism

just touching your eye. Can you see the flame through the prism? Where does the flame appear to be? Now turn the prism round counter clockwise—*i.e.* the summit of the prism approaches your eye. What happens to the flame?

2. Draw normals to the surfaces of the prism at A and B and find the index of refraction of the ray (1) entering at A (2) emerging at B. Is there any relation between the answers?

3. Take the figure of the experiment and draw a normal to the prism at A and at B. Let the normals meet at the point T. Let α be the angle between the ray CA and its normal, and β the angle between the ray DB and its normal. Let α' and β' be the angles between the ray AB and the normals at A and B respectively. Let D be the angle of deviation. Mark these angles on your figure.

Measure each of these angles and so show that

$$\angle\alpha + \angle\beta = \angle D + \angle P \text{ and } \angle\alpha' + \angle\beta' = \angle P.$$

Repeat for different positions of the ray CA.

The relations can also be proved by geometry.

Notice (1) $\angle OAB + \angle OBA = \angle D$ (exterior angle).

(2) $\angle P + \angle T = 180^\circ$ since PATB is a quadrilateral with two right angles.

Now $\angle\alpha + \angle\beta = \angle OAT + \angle OBT$ (vertically opposite angles)

$$= \angle OAB + \angle\alpha' + \angle OBA + \angle\beta'$$
$$= \angle OAB + \angle OBA + \angle\alpha' + \angle\beta'$$
$$= \angle D + \angle\alpha' + \angle\beta'$$

Now $\angle\alpha' + \angle\beta' + \angle T = 180^\circ$

and $\angle P + \angle T = 180^\circ$

$\therefore \angle\alpha' + \angle\beta' = \angle P$

$\therefore \angle\alpha + \angle\beta = \angle D + \angle P.$

EXPERIMENT **34**

To find the Path of Minimum Deviation through a Prism

Apparatus—*Prisms*; *Pins*

Set the prism upright on a sheet of paper and turn it till an edge is nearest you. Look through one surface, and stick a pin upright 1 cm. behind the prism so that you can see it through the prism. Rotate the prism slowly. The pin appears to move in one direction and then turn back. Arrange the prism in the position where the pin just begins to move back.

Keeping your eye fixed on the pin, insert two pins, one touching the front and one the back surface of the prism so that these two pins appear in a straight line with the first pin. Insert another pin between your eye and the prism so that the four pins appear in a straight line. Draw a line on the paper round the prism. Remove the prism, measure the angles of incidence, emergence, and deviation. Find the angle of deviation in other positions, and compare the size.

EXERCISES

1. Find the connection between the angle of refraction at one surface of the prism, and the angle of the prism, when there is minimum deviation (see Ex. 3 of last experiment).

2. Show that the Index of Refraction $= \dfrac{\text{Sine}\ \dfrac{D+P}{2}}{\text{Sine}\ \dfrac{P}{2}}$ where D = angle of minimum deviation, P = angle of prism.

(See figure in Exp. 33. In minimum deviation $\alpha=\beta$ and since $\alpha+\beta = D+P$ (see Ex. 3, Exp. 33) $\therefore \alpha = \dfrac{D+P}{2}$; also $\alpha' = \beta'$ $\therefore \alpha' = \dfrac{P}{2}$.)

3. The angle of a prism is 30° and its index of refraction is $\frac{3}{2}$. What is the minimum deviation? (Use table of Sines.)

4. Find the index of refraction of a prism where the angle of the prism is 60° and the minimum deviation 38°.

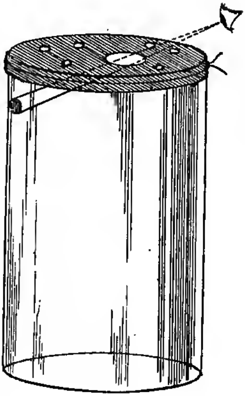
EXPERIMENT **35**

Total Reflection and Critical Angle

Apparatus—*Glass Jar or Beaker without a spout*; *Sheet of Paper*; *Thread*; *Gummed Paper*

Cover the mouth of a beaker with a stout sheet of paper, tying the paper with thread as you would a jam-pot cover.

In the centre of the paper cut a round hole about 1 cm. diameter, and also make several small air holes.

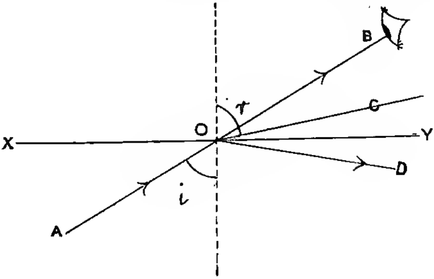


On the outside of the beaker gum a narrow horizontal strip of paper (coloured, so that it may be seen easily). This paper should be gummed so high on the side of the beaker that a person looking through the round hole in the paper cover as horizontally as possible is just able to see the top of the strip.

Keeping your eye fixed on the coloured strip through the hole in the cover, pour water gently into the beaker through the hole till the water reaches the level of the hole. Can you now see the coloured strip?

In the diagram, let A be the coloured strip and O the hole. Then AOB is the path of a ray from A to the eye when there is no water in the beaker.

When the water is in the beaker, let XY be the surface of the water. The ray AO is refracted at O (why?), and since the ray is passing from one medium (water) into a rarer medium (air) it is bent from the normal (say along the line OC).



$\therefore \frac{\text{Sine } i}{\text{Sine } r}$ is less than 1 (since $i < r$).

In the case of a ray passing from water into air it is found that the refractive index $\frac{\text{Sine } i}{\text{Sine } r} = \frac{3}{4}$.

Now if the angle i is such that its sine $= \frac{3}{4}$, we see that sine $r = 1$. In this case $r = 90°$ (see Table of Sines), and the ray AO will be refracted along OY.

If the angle i is such that its sine is greater than $\frac{3}{4}$, then sine r is greater than 1. This is impossible; therefore there can be no refraction, and the ray AO does not pass into the air at all, but is reflected at the surface of the water along a path OD in the water.

When sine $i = \frac{3}{4}$, the angle $i = 48° 45'$. When i is greater than $48° 45'$ the ray AO does not pass into the air, but along a path (*e.g.* AOD) in the water. The ray AO is said to be *totally reflected* at O.

The angle $48° 45'$ is called the *Critical* or *Limiting Angle* for water into air. ∴ Sine of Critical Angle $= \frac{1}{\text{Index of Refraction}}$ (since Index of Refraction $= \frac{\text{Sine } i}{\text{Sine } r}$, and in this case Sine $i = 1$ and $r =$ Critical Angle).

The Critical Angle may be defined thus:

If a ray travelling in a medium reaches a plane surface of that medium in such a direction that it passes along this surface (and so does not emerge from the medium), the angle which the ray (incident to the surface) makes with the normal is called the Critical Angle.

The Critical Angle for a ray passing from glass into air is about 42°.

Note that when the rays travel so that i is less than the critical angle most of the rays are refracted, but *some* are reflected at the surface. When, however, i is equal to or greater than the critical angle, *all* the rays are reflected.

EXERCISES

1. Place a coin in the bottom of a beaker (touching the side), and pour water into the beaker to a depth of about

1 cm. Hold the beaker above your head, and look up through the water at the surface of the water. Move the beaker about. Can you see the reflection of the coin?

2. Plunge an empty test-tube (closed end downward) obliquely into a beaker full of water. Note the part of the test-tube under water. What is its appearance? [For the best results the light should be horizontal.] Can you give any reason for the shining appearance? Pour water into the test-tube. Is there any change in the appearance?

3. Take a stirring rod and gum a small piece of paper on it 2 or 3 inches from the foot. Place the rod in a beaker, and add water till within half-an-inch of the paper. Hold the beaker so that the top of the water is a little above your eye, and look obliquely up through the water. Can you see the paper in all positions? If not, why not?

4. Look obliquely at a crack in a pane of glass. What appearance has it? Why?

5. Look at an air bubble in a sheet of glass or in a glass slab. Explain its glistening appearance.

6. Explain how the Critical Angle may be got if the Index of Refraction is known. The Index of Refraction of window glass is about 1·5, what is the Critical Angle? (Use table of Sines at the end of this book.)

EXPERIMENT **36**

Reflection in a Prism

Apparatus—*Ordinary Triangular Prism*; *Paper*; *Pins*

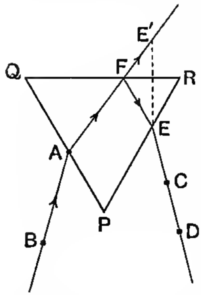
Pin a sheet of paper on the bench, and place an ordinary triangular prism upright on it. Draw on the paper a line PQR round the perimeter of the prism.

Stick a pin A upright against the surface PQ of the prism, and another pin B a few centimetres in front of the same surface, so that the line BA cuts the surface obliquely.

Look along BA, and move a pin C in front of the surface PR. In one position you will see the pin C *faintly*. This is the image of C reflected from a surface of the prism. (Which surface?) If a sheet of black paper is placed behind QR the image is seen better.

Arrange C so that B, A, and the image of C appear in a straight line.

Insert a pin D in front of the surface PR so that B, A, and the images of C and D are in a straight line.



Remove the prism, join DC, and produce it till it meets PR in E. Then E is a point in the path of the ray BA, and so its image will be in a straight line with B and A.

If a pin were placed at E, the image of E in the surface QR would be at E′ behind QR (how far?). Mark E′.

Join AE′, cutting QR in F. The ray BA travels from A to F, is reflected at F to E, and emerges along ECD. Place a pin at F and find if B, A, F appear in a straight line. Is the whole of the light reflected, or does some of it travel beyond QR? Test this by placing a pin behind QR.

Mark the position of the image of C.

EXERCISES

1. Stand in front of a window with your back to it, and hold an equilateral prism upright with one vertical surface (say AB) parallel to the window. Look into another surface AC so that you see the image of the sky reflected from the rectangular base BC. Turn the prism round, and notice the change from a faint to a bright light. When the two lights are seen at the same time what is between them? The bright light is due to the total reflection of the light incident upon BC.

2. Place an ordinary prism flat on a page with writing on it, and look vertically down at the writing through the prism. Can you see it? Gradually lower your eye, still looking at the writing. Does the writing remain visible? Do you notice anything peculiar about the appearance of the prism? Can you give the reason?

EXPERIMENT **37**

Total Reflection in a Prism

Apparatus—*Sheet of Paper*; *Isosceles Right-angled Prism*; *Pins*

Pin a sheet of paper on the bench. On it place a right-angled prism upright, and draw on the paper a line ABC round its perimeter.

Draw a line perpendicular to AB to cut it near the middle. On this line stick two pins P and Q upright a few centimetres in front of AB. A ray along PQ enters the prism. Is this ray refracted? What will be its path?

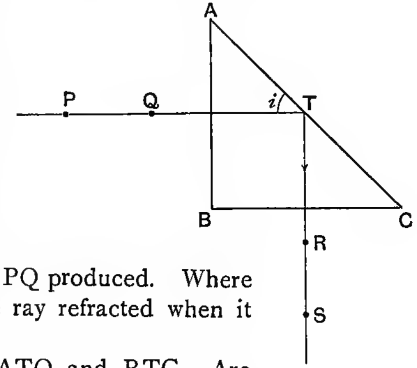
When the ray PQ reaches AC it is either refracted into the air or reflected back into the prism.

When will it be reflected back into the prism? (See Exp. 35.)

Measure the angle of incidence *i*. The critical angle from glass into air is about 42°. Is *i* greater or less than this? What happens to the ray PQ when it reaches AC?

Look into the prism through the face BC, and stick two pins R, S in front of BC so that P, Q, R, S appear in a straight line.

Remove the prism, join RS, and produce the line SR till it meets PQ produced. Where do they meet? Is the ray refracted when it reaches the surface BC?



Measure the angles ATQ and RTC. Are they equal?

Since these two angles are equal the surface AC acts as a plane mirror.

Note that the angles A and C do not require to be 45°. As long as they are greater than the critical angle, the rays will be reflected at AC.

EXERCISES

1. How would you use a right-angled prism to enable you to see round a corner?

2. A prism having angles 45°, 45°, 90° is placed on the hypotenuse surface. Two rays parallel to the hypotenuse strike one of the other surfaces, and emerge from the third surface. Prove by drawing or geometry that the rays will emerge still parallel to the hypotenuse.

EXAMINATION PAPER ON REFRACTION

1. What do you mean by "Refraction"? State the Laws of Refraction. What is "Index of Refraction"? A ray of light passes from air into glycerine. How is the direction of the ray altered?

2. Why is it that a pool of clear water appears shallower than it really is?

3. Define Incident Ray, Emergent Ray, Angle of Deviation.

4. Make a sketch to show the path of a ray through a triangular prism.

5. A person looking at an object through a prism sees the object displaced towards the apex of the prism. Explain this.

6. What is meant by "Total reflection in a prism"? What must be the shape of the prism? Describe any experiment, showing total reflection (not using a prism).

7. Rays of light from a candle strike obliquely a rectangular glass slab. Trace the path (or paths) of the rays.

8. A stick is plunged obliquely into water. Make a sketch of its appearance to an observer.

9. What happens to a ray of light when (1) a slab of glass, (2) a prism is placed across its path?

CHAPTER VI

REFRACTION THROUGH LENSES

EXPERIMENT **38**

To find by Inspection if a Lens is Convex or Concave

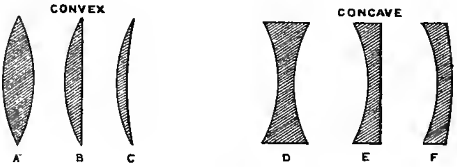
Apparatus—*Convex and Concave Lenses* (*of high Power*)

First Method

LOOK at the lenses given you. Notice that some are thicker at the centre than at the edges. These are called *Convex Lenses.* Convex lenses (for a reason which you will afterwards find out) are sometimes called *Converging Lenses.*

Other lenses are thinner at the centre than at the edges. These are called *Concave* or *Diverging Lenses.*

The diagram shows the various forms of lenses.



A, *Double Convex;* B, *Plano-convex;* C, *Concavo-convex or Convex Meniscus.*

D, *Double Concave*; E, *Plano-concave*; F, *Convexo-concave or Concave Meniscus.*

Take each of the convex lenses in turn, and hold it at the edges between a finger and the thumb. Hold the lens in front of a page of writing or printed matter, almost touching it, and look through the lens.

Move the page about (if necessary) till you can read the words distinctly. Then slowly move the lens away from the page, and notice if the writing increases or diminishes in size.

Repeat this with each of the concave lenses.

Repeat with a piece of plain glass (*i.e.* glass with the two opposite surfaces parallel or concentric). State what happens in each case.

Second Method

Hold a convex lens between your eye and an object, and move the lens about till you see the object erect.

Move the lens slowly upward and downward in front of your eye. How does the object appear to move?

Repeat with the other lenses and with a piece of plain glass.

State the two rules for finding if a lens is convex or concave.

EXERCISES

1. Find if the pieces of glass given you are convex, concave, or plain.

2. Perform the experiment with an ordinary watch glass. What do you infer?

EXPERIMENT **39**

To find the Position and Size of the Image formed by a Convex Lens

Apparatus—*Convex Lens* (10-20 *cm. focal length*); *Stand* (*same as that used for holding Spherical Mirrors*); *Candle or Gas Flame*; *Blocks of Wood*; *Gauze Screen*; *Clamp Stand*

Make a screen of paper with a triangular hole of gauze (see Exp. 20). [An ordinary candle flame can be used with the gauze screen.]

Fix the lens vertically in a stand, and clamp the gauze screen vertically in a clamp stand.

Arrange the lens and the gauze screen parallel, and place a flame on the other side of the screen from the lens. The lens, gauze, and candle should be at the same height—*i.e.* a line (called the *Principal Axis*) through the centre of the lens and perpendicular to the faces should pass through the centre of the gauze and of the flame.

Place the lens 8 or 10 cm. from the gauze, and look horizontally through the lens at the gauze, your eye being at least a metre from the lens.

Fill in the answers to the questions in the table. (The object in the table is the gauze.)

1 Distance of Object from Lens	2 Is Image erect or inverted?	3 Is Image magnified or diminished?	4 Is image nearer or farther than Lens from Observer?	5 Is Image nearer or farther than Object from Observer?	6 Is Image between the Lens and the Object?	7 Can the Image be received on a Sheet of Paper?

Get the answer to (4) by the method of relative motion.

If the image is in front of the lens (*i.e.* between the eye and the lens) place a vertical sheet of paper in front of the lens, and move it backward and forward to see if the image can be received on the paper.

If you find by the method of relative motion that the image is behind the lens, then you know that the image is either between the lens and the object or behind the object. Put a mark on the screen (say a vertical line) above the gauze. Look through the lens so that you see the image of the gauze, and also see the mark above the lens (*i.e.* the mark is not seen through the lens). Find now by the method of relative motion if the image is in front or behind the mark, and so get the answer to (5).

If the image is found to be between the lens and the object place a small piece of paper (fixed on a pen) between the lens and the object, and try to receive the image on the paper.

If the image is found to be behind the object place a sheet of paper behind the object, and try to get the image on it.

Repeat the experiment several times, moving the lens each time a few cm. farther from the gauze.

Is the image a real or a virtual image?

EXERCISE

Place the lens near the gauze, and looking through the lens draw it slowly back from the gauze, always keeping your eye a metre away from the lens. At one point the image will become indistinct. Move the lens farther from the gauze. Is there any change in the image?

EXPERIMENT **40**

To find the Position and Size of the Image formed by a Concave Lens

Apparatus—*Concave Lens* (10-20 *cm. focal length*); *Same Apparatus as Exp.* 39

Perform the experiment in the same way as Exp. 39, and fill up a similar table.

Make a note of the differences between the images seen through a convex lens and through a concave lens.

Is the image seen through a concave lens a real or a virtual image?

EXPERIMENT **41**

To find the Focal Length of a Convex Lens

First Method

Apparatus—*Convex Lens* (10-20 *cm. focal length*) *with Stand*

Hold the lens as far as possible from a flame, one surface of the lens facing the flame.

Place the back of your hand against the other side of the lens, and slowly draw your hand away from the lens till a bright spot is seen on your hand. Move the lens a little till the spot is brightest.

Measure or guess the distance between the spot and the lens. This gives roughly the focal length of the lens.

Rays which reach the lens in a direction parallel to the principal axis all pass through a point on that line which is called the *Principal Focus.* The distance between this point and the centre of the lens (measured along the principal axis) is called the *Focal Length.*

If you are asked to find the focal length of a convex lens always get a rough answer by the above method, and then get the exact answer by the second or third method.

Second Method

Apparatus—*Wire Gauze Screen* (*see Exp.* 20); *Flame*; *Paper Screen to receive Image*; *Convex Lens with Stand*

Draw a chalk line along the bench.

Arrange the lens and the gauze screen above the chalk line parallel to each other and at the same height above the bench. Place the image screen on the side of the lens away from the gauze. [The distance between the gauze and the image screen should be greater than four times the focal length which was found roughly by the first method.]

Move the lens close up to the gauze, and place a flame behind the gauze.

Slowly move the lens away from the gauze (along the chalk line) till an image of the gauze is seen on the image screen.

Move the screen slightly till the image is as distinct as possible. (If no image is seen, increase the distance of the screen from the gauze and repeat.)

Measure the distance between (1) the lens[1] and the gauze; (2) the lens and the image.

Repeat for other positions of the screen, and arrange your answers in a table.

Distance between Lens and Object (u)	Distance between Lens and Image (v)	$\frac{1}{v}-\frac{1}{u}$

In finding the value of $\frac{1}{v}-\frac{1}{u}$ remember the Rule of Signs (see Exp. 22) that all distances measured from the lens towards the object or flame are positive. What are the signs of u and v in this case?

Then $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ where f is the focal length of the lens.

As parallel rays on passing through a convex lens come to a focus on the side remote from the object, it follows that f is *negative* for a convex lens.

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[1] The distance should be measured from the middle or Optical Centre of the lens (*i.e.* half way between the two surfaces in a double convex lens), but if the lens is thin you can neglect the thickness of the glass.

Third Method

Apparatus—*Gauze Screen; Convex Lens in Stand; Plane Mirror* 6″ × 6″

Place the gauze and the lens parallel and at the same height above the bench. The distance between the gauze and the lens should be about the focal distance found by the first method. Behind the gauze place a light.

Behind the lens (*i.e.* on the side away from the gauze) place a plane mirror vertical and parallel to the lens.

Turn the mirror a very little to one side, and move the lens backward and forward till a distinct image of the gauze is seen on the screen beside the gauze.

Measure the distance between the lens and the image. This distance is the focal length.

Proof:

Rays of light from the flame pass through the lens and reach the mirror in various directions. These rays are reflected from the mirror according to the laws of reflection, therefore those rays which strike the mirror normally are reflected back along their incident paths. These normal reflected rays are therefore parallel.

These reflected parallel rays pass through the lens again, and form an image of the gauze on the screen. If rays are parallel, then they are said to come from a light at an infinite distance. [Give an example.] ∴ In the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, u = infinity. $\therefore \frac{1}{u} = 0$. $\therefore \frac{1}{v} - 0 = \frac{1}{f}$. $\therefore \frac{1}{v} = \frac{1}{f}$—*i.e.* the distance of the image from the lens equals the focal length.

Note.—To prove formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ (see figure for Exp. 43).

By similar triangles $\frac{CT}{Ct}=\frac{PT}{pt}$ and $\frac{DC}{pt}=\frac{CF}{Ft}$.

Let $CT=u$; $Ct=-v$; $CF=-f$ (negative because measured in the direction away from the object).

Then $\frac{u}{-v}=\frac{CT}{Ct}=\frac{PT}{pt}=\frac{DC}{pt}=\frac{CF}{Ft}=\frac{CF}{Ct-CF}=\frac{-f}{-v+f}$.

$\therefore -uv+uf=vf$. $\therefore f(u-v)=uv$. $\therefore \frac{u-v}{uv}=\frac{1}{f}$. $\therefore \frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

EXERCISES

1. Draw a graph of the corresponding values of u and v, also a graph of the corresponding values of $\frac{1}{u}$ and $\frac{1}{v}$.

2. Arrange the apparatus as in the Second Method, and get a distinct image. Note the exact positions of the object and the image from the lens. Place the object in the position of the screen, and the screen in the position of the object. Do you get a distinct image on the screen? These interchangeable positions of the object and the image are called *Conjugate Foci.*

EXPERIMENT 42

To find the Magnification produced by a Convex Lens

Apparatus — *Same as last Experiment* (*Second Method*); *Dividers*

Arrange the apparatus so as to get a distinct image on the screen.

With a pair of dividers measure the length of a certain number of meshes of the gauze and the length of the same number of meshes on the image. Also measure the distance of the object and of the image from the lens (i.e. u and v).

Repeat for other positions of the object and arrange your results in a table.

Size of Object	Size of Image	Magnification = $\frac{\text{Size of Image}}{\text{Size of Object}}$	u	v	$\frac{v}{u}$

Exercises

1. A pin 1 inch high is placed 2 feet from a convex lens (f= 1 foot). Where is the image? What is the height of the image?

2. A circular disc of paper is placed 30 cm. from a convex lens of 10 cm. focal length, and an image 1·5 cm. diameter is formed on a screen. What is the diameter of the disc?

3. A flame 10 cm. high is placed 20 cm. from a convex lens, and the image on a screen is 5 cm. high. What is the focal length of the lens?

4. A flame 1 cm. high is placed 20 cm. from a convex lens and a *virtual* image 10 cm. high is formed. What is the focal length of the lens?

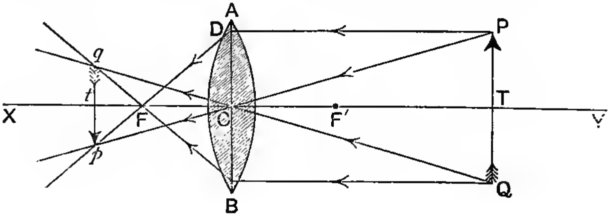
EXPERIMENT **43**

To find, by drawing, the Position and Size of the Image formed by a Convex Lens

Apparatus—*Straight Edge*; *Compasses*

Draw a line XY to represent the principal axis. Let AB be a thin convex lens. (The lens acts as a number of truncated prisms with the bases towards the centre of the lens, but when the lens is thin we may neglect the effect of refraction at the two surfaces of the lens and suppose the rays to be bent once at the straight line AB.)

Mark a point F on XY to the left of the lens. Let F be the principal focus. CF is called the focal length (*f*). Then



all rays which reach the lens parallel to the principal axis XY will pass through the focus F. Mark a point F′ on the right of the lens at the same distance from the centre (C) of the lens as F.

A body may have four positions: (1) it may be at a greater distance from the lens than twice the focal length (*f*); (2) it may be at a distance greater than *f* and less than 2*f*; (3) it may be at the same distance as *f*; (4) it may be at a less distance than *f*.

Draw a vertical arrow PQ to the right of F′, at a distance from C greater than 2*f*.

From P draw two rays, one through the centre C, which continues in a straight line (because the part of the lens through which this ray passes is practically a very thin slab or plate, and therefore the ray suffers no deviation by refraction), another parallel to the axis XY, and refracted through the principal focus. The intersection of these two rays at *p* marks the position of the image of P. Repeat with the point Q.

From the drawing tell if the image is real or virtual, erect or inverted, enlarged or diminished, nearer or farther from the lens than the object is.

Repeat the drawings for the other three positions of the object and write your results in a table.

EXERCISES

1. Make out a table of results similar to that shown in Exp. 23.
2. By actual measurement of the drawing prove that the formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ is correct.
3. By measurement prove that the Magnification $=\frac{v}{u}$.

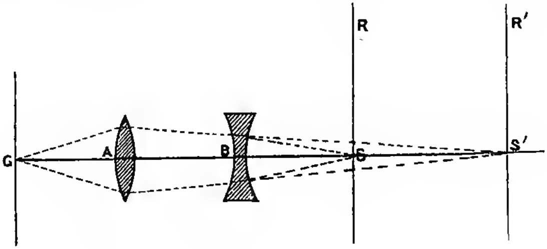
EXPERIMENT **44**

To find the Focal Length of a Concave Lens

First Method

Apparatus—*Concave Lens* (*say* 10-20 *cm. focal length*) *on Stand*; *Convex Lens used in Exp.* 41; *Gauze Screen*; *Image Screen*; *Flame*

There is no direct way of finding the focal length of a concave lens since the image formed is virtual, and cannot be received on a screen.



Draw a chalk line along the bench. Arrange the gauze screen (G) with a light behind it, the convex lens (A), and the image screen (R) so that a real image of the gauze is formed on the image screen. [*Note.*—In the diagram the lines from S (not S′) through the two lenses should be straight.]

Mark the position of the image screen (RS).

Place the concave lens (B) between the convex lens and the image screen, about 5 cm. from the screen (*i.e.* less than the focal length of the concave lens), and move the screen away till a distinct image of the gauze appears on it. Mark the new position of the screen (R′S′).

Measure the distances BS and BS′.

S′ may be regarded as a source of light. The rays travel from S′ to the concave mirror, are refracted so as to diverge more, and thus appear to form an image at S; ∴ $BS' = u$ and $BS = v$, and since they are on the same side of the concave lens they are both positive.

Calculate the focal length of the concave lens from the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$.

Repeat several times for different positions of the concave lens, and take the average of the values of f. Arrange your answers in a table.

What is the sign of f for a concave lens?

Second Method

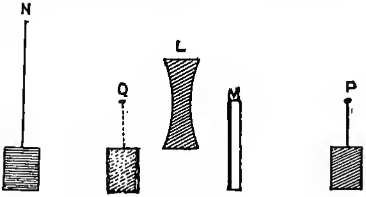
Apparatus—*Concave Lens on Stand*; *Pin stuck in Block of Wood*; *Long Needle stuck in Block of Wood*; *Plane Mirror*

Place the lens (L) and the plane mirror (M) vertical and parallel so that the face of the mirror is away from the lens. The top of the mirror should be on a level with the principal axis of the lens.

A few centimetres in front of the mirror (*i.e.* on the side away from the lens) place a pin P (stuck on a block). The top of P should at least be as high as the top of the mirror.

Look into the mirror, and an image of P will be seen at Q. (Compare the distances PM and QM.)

Place a long needle (N) on the other side of the lens from P and about 20 cm. from the lens. The top of this needle should be as high as the top of the lens.



Place your eye in front of P, and look at the mirror and through the lens. At the same time you see two images, (1) the image of P in the mirror; (2) the image of N through the lens.

By the method of relative motion find which of the two images is nearer to you.

Move P backward or forward as is required till the two images always coincide.

Then the distance from N to the lens $= u$, and the distance from Q to the lens $= v$, since Q marks the position of the image of N.

Measure these distances. [Note that QM = PM. ∴ QL = PM − LM.]

Use the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ to find f.

Repeat, with the needle N at various distances from the lens, and take the average value of f. Arrange your results in a table.

Note.—To prove formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ for concave lens (see figure, Exp. 45).

Let $CT = u$; $Ct = v$; $CF = f$ (all positive).

By geometry $\frac{CT}{Ct} = \frac{PT}{pt}$ and $\frac{DC}{pt} = \frac{CF}{Ft}$ (similar triangles).

$$\therefore \frac{u}{v} = \frac{PT}{pt} = \frac{DC}{pt} = \frac{CF}{Ft} = \frac{f}{f-v}.$$

$$\therefore uf - uv = vf. \quad \therefore f(u-v) = uv. \quad \therefore \frac{1}{v} - \frac{1}{u} = \frac{1}{f}.$$

EXERCISE

The focal length of a concave lens can be found by combining the lens with a stronger convex lens.

Place a convex lens in front of and touching the concave lens. Look through the combination, and find if it acts as a convex or a concave lens. Repeat with other convex lenses till a combination is got which is distinctly convex. Find the focal length of the convex lens and of the combination (treating the combination as a convex lens). If f_1 = focal length of convex lens, f_2 = focal length of the combination, and f = the focal length of the concave lens, then

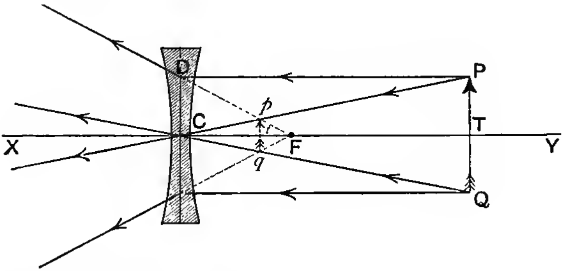
$$\frac{1}{f}=\frac{1}{f_1}-\frac{1}{f_2}.$$

EXPERIMENT **45**

To find, by drawing, the Position and Size of the Image formed by a Concave Lens

Apparatus—*Straight Edge*; *Compasses*

Draw an axis XY and a concave lens across it. Let PQ be an object to the right of the lens. Then a ray from P passing through the centre C of the lens is not refracted but passes straight on. Also a ray from P parallel to the axis XY diverges when it passes through the lens and appears



to come from a point F. F is the *virtual* principal focus (why "virtual?").

By drawing these two rays from P and Q find the position of the image pq.

Make drawings for the following positions of the object: (1) at a greater distance from the object than $2f$; (2) between $2f$ and f; (3) less than f.

Is the image real or virtual, erect or inverted, enlarged or diminished, nearer or farther from the lens than the object is?

EXERCISES

1. A short-sighted person can see an object best when it is 20 cm. from his eye. He wishes to see distinctly an object 5 metres away. What kind of lens must he use? What will be its focal length? (Here $u = 5$ metres; $v = 20$ cm.)

2. Since $\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \therefore \frac{u-v}{uv} = \frac{1}{f} \therefore uf - vf = uv \therefore v(u+f) = uf$ $\therefore \frac{v}{u} = \frac{f}{u+f}$.

From this relation show that in a concave lens the image is always less than the object. Is this true of a convex lens? (Remember the rule of signs.)

NOTE ON LENSES

The effect of a convex lens is to bring rays to a focus, and that of a concave lens to diverge the rays. In other words, a convex lens has the positive power of increasing the convergence, while a concave lens decreases the convergence. It is easily proved that this power is measured by the reciprocal of the focal length.

The unit of power used is called a *Dioptre*. A convex lens whose focal length is 1 metre is said to have a converging power of 1 Dioptre, or 1 D.

$\therefore \frac{1}{1 \text{ metre}}$ represents 1 D.

Thus a convex lens of 50 cm. focal length would have a wer of $\frac{1}{\frac{1}{2}\text{ (metre)}}$D. = + 2 D. The sign + is placed before the power to show that the lens increases the convergence—*i.e.* a *convex lens* is said to have a *positive* power. [Note that this is the opposite sign from the focal length, which is negative.]

This notation is used by oculists and opticians. For example, an oculist's prescription may read thus:

Right Eye	Left Eye
– 1·25 D.	– 1·5 D.

An optician knows from this that the lens for the right eye is *concave*, and has a focal length of $\frac{1}{1\cdot25}$ metre, and that the lens for the left eye is also concave, with a focal length of $\frac{1}{1\cdot5}$ metre.

EXAMINATION PAPER ON REFRACTION

1. A piece of glass is given you. How would you test if the glass were plane or curved?

2. Describe a method of finding the focal length of a convex lens approximately.

3. Is there any relation between the focal length of a lens and the positions of an object and its image seen through the lens? Can you write the relation as an equation? The focal length of a convex lens is 10 cm., and a pin is placed 30 cm. in front of the lens. Where is the image?

4. A pin is set up in front of a convex lens 15 cm. focal length. Where must the pin be placed so that the image is (1) erect; (2) inverted; (3) real; (4) virtual?

5. What is meant by the Magnifying Power of a lens? An object is set 20 cm. in front of a convex lens of 5 cm. focal length. Compare the sizes of the object and its image.

6. What is the nature of the image in a concave lens—*i.e.* is it real or virtual, erect or inverted? Describe a method of finding the focal length of a concave lens.

7. What is meant by Radius of Curvature, Principal Focus, Principal Axis, Conjugate Foci?

8. What is a Dioptre? What kind of lens is denoted by (1) + 4 D.; (2) – 1·7 D.?

CHAPTER VII

SIMPLE OPTICAL INSTRUMENTS

EXPERIMENT **46**

The Simple Microscope

Apparatus—*Small Double-Convex Lens* (*say* 3 *to* 5 *cm. focal length*)

TAKE a double-convex lens of short focal length and hold it between your finger and thumb. Hold the lens in front of and almost touching your eye, and look through it at the back of your hand, or at a hair lying on a glass plate. (Your hand or the hair should be in a good light.) Move the lens (keeping it close to your eye) slowly away from the object till you can see the object distinctly.

Very slowly move your eye and the lens farther from the object. What do you notice about (1) the change of size of the object; (2) the change of distinctness?

Find the focal length of the lens if you do not know it. Look through the lens at the object, and move it till the most distinct position is got. Get your neighbour to measure the distance between the object and the lens. Compare this distance with the focal length of the lens. Which is greater?

Draw a double-convex lens, place an arrow (to represent an object) between the lens and its principal focus, and by construction find if the image is real or virtual, enlarged or diminished, nearer or farther from the lens than the object is. (See Exp. 43.)

Note.—The apparent size of an object as seen through a lens depends on the angle which it subtends at the eye. As the object approaches the eye, the larger it will appear. But there is a limit to the nearness to the eye. There is a least distance of most distinct vision—*i.e.* an object must not be placed nearer to the eye than this distance (usually about 10 inches) if it is to be distinctly seen. Test this by holding a vertical pencil so that the point is 2 or 3 inches in front of your eye, and try if you can see it distinctly without straining your eyes. Therefore the magnification by a simple microscope has a limit. The lens must be placed at such a distance from the object that the image formed is at the distance of most distinct vision from the eye. If the lens is placed nearer than this the image is blurred.

The magnification (when the eye is very near the lens) can be found as follows:

For a convex lens $\frac{1}{v} - \frac{1}{u} = -\frac{1}{f}$ (since focal length is negative)

v = distance of image = distance of distinct vision which is known.

$$\therefore \frac{1}{u} = \frac{1}{v} + \frac{1}{f} = \frac{f+v}{vf} \qquad \therefore u = \frac{vf}{f+v}.$$

$$\text{Magnification} = \frac{v}{u} = \frac{v}{\dfrac{vf}{f+v}}$$

$$= \frac{f+v}{f}$$

∴ to find the magnification, divide the sum of the focal length and the distance of distinct vision by the focal length.

EXERCISES

1. A lens has a focal length of 3·5 cm. The least distance of distinct vision is 25 cm. Find the magnification.

2. One person has a lens 5 cm. focal length. His least distance of distinct vision is 25 cm. Another person whose least distance is 30 cm. looks through another lens and sees the same object as much magnified as the first man saw it.

What is the focal length of the second lens? If the two men looked through the same lens, which man would see the object more magnified?

3. A simple microscope may be made as follows: Heat the middle of a piece of thin glass rod or tubing in a bunsen. When it is soft draw the ends apart. Put the end having a thread of glass into the flame, so that a small globule of glass is formed at the end. Heat carefully so that the globule is as round as possible. Take a thin shaving of cork, thinner than the diameter of the globule, and make a small hole through it large enough to hold the globule tightly. Break the globule from the thread, remove any ragged edge and fit it into the cork. This gives a simple microscope. Place a hair on a glass slide and examine it through the globule, holding the globule very near your eye.

4. Fill a round-bottomed flask with water and look through it at some small object held near to it, moving the object till it is seen distinctly. What do you notice?

5. A convex lens is employed (1) in forming a real image of a distinct object; (2) as a magnifying glass. Show by means of diagrams the positions of the lens.

EXPERIMENT **47**

To construct a Model of a Compound Microscope

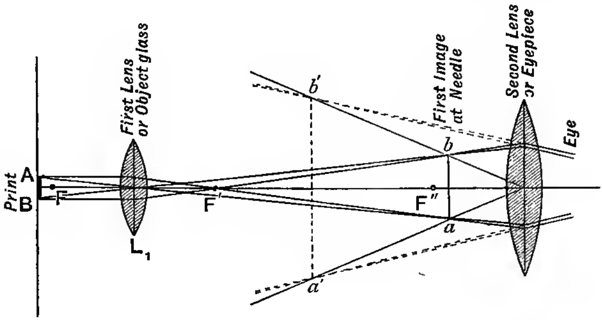
First Method

Apparatus—*Two Small Double-Convex Lenses, about* 3 *to* 5 *cm. focal length; Vertical Needle on Block of Wood; Page of Small Printed Matter; Stands for Lenses; Blocks of Wood.*

Set the printed page vertically at the end of the bench. Place one of the lenses L_1 (the one with the shorter focus if the two are not the same) in front of the page, a short distance from it.

Stand about half a metre from the lens and look through it at the print. If the image is erect, withdraw the lens from the print till an inverted image is seen. If an inverted image is seen, move the lens nearer the print till the *inverted* image is as large and distinct as possible. (You will find that the lens is now a little more than its focal distance from the print.)

This image is a real image. Place the vertical needle between your eye and the lens, and by the method of relative motion make the needle coincide with the image.



Place the second lens L_2 between your eye and the needle, about 3 or 4 cm. from the needle and in a line with the other lens, and move it till an enlarged image of the needle is seen distinctly. (The eye should almost touch the lens.) Remove the needle and look through the two lenses at the print. Is the image erect or inverted?

Second Method

Apparatus—*Same as First Method*; *Candle*; *Sheet of White Paper*

Instead of the printed page set up a lighted candle, and place the lens L_1 a short distance in front of it.

Stand about half a metre from the lens and look through at the flame. Move the lens away from the flame till a distinct *inverted* image is seen.

Place a sheet of white paper behind the lens (*i.e.* on the side away from the flame), and move the sheet about till the inverted image of the flame is distinctly seen on it.

Place the second lens L_2 one or two centimetres behind the sheet of paper, so that the two lenses and the flame are in a straight line. Remove the sheet of paper and look through the lenses at the flame, keeping your eye close to the second lens. Move this lens slightly till a distinct image of the flame is seen.

Remove the flame and place a vertical page of printed matter in its place. Look through the lenses at the print.

Note.—In a compound microscope the action is as follows: (1) the first lens L_1 (called the *object glass* or *objective*) produces an inverted and enlarged real image of the object; (2) the second lens L_2 (called the *eye-piece* or *ocular*) acts as a simple microscope on this image, forming an enlarged virtual image (for method see Exp. 43). The diagram shows the paths of the rays.

EXPERIMENT **48**

To construct a Model of an Astronomical Telescope

Apparatus—*Double-Convex Lens, about* 30 *cm. to* 70 *cm. focal length*; *Small Double-Convex Lens,* 3 *cm. to* 5 *cm. focal length*; *Stands for Same*; *Block of Wood with Vertical Needle attached*; *Page of Large Type* (*the type being at least* ½ *in. high*) *pinned on Wall at the Level of the Bench*

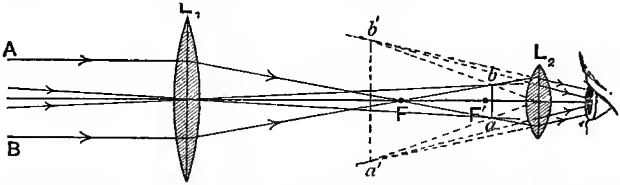
Set the page of large type as far away as possible, and place the long focus lens on the bench parallel to it. Look through the lens at the print, standing about half a metre away from the lens. What do you see? Find by the method of relative motion if the image is real—*i.e.* between your eye and the lens.

Place the knitting needle between your eye and the lens, and by the method of relative motion get the needle to coincide with the image.

Set up the short focus lens between your eye and the needle in a line with the other lens. Move the short focus lens till it is about its focal length from the needle. Place your eye near this lens and look at the needle. Move the lens slightly till the needle is clearly seen through it.

Remove the needle and look through the two lenses at the print. What do you see?

The long focus lens (the *object glass*) forms an inverted diminished image of the object near the focus. (When the object is at a great distance, *e.g.* a star, the rays of light from the object are parallel and the image is formed at the focus.) The short focus lens (the *eye-piece*) acts as a magnifying glass, and is placed so that the image formed by the object glass is between the eye-piece and its focus. The diagram shows the direction of the rays; AB is the print; *ab* the image formed by the object glass; *a′b′* the enlarged image formed by the eye-piece.



Note.—Instead of a needle and a page of print, a candle flame and sheet of paper may be used as in Exp. 47 (second method).

EXPERIMENT **49**

To construct a Model of Galileo's Telescope

Apparatus—*Double-Convex Lens* (25 *cm. to* 30 *cm. focus*); *Small Double-Concave Lens* (*about* 10 *cm. focus*); *Vertical Needle on Block of Wood*; *Stands for Lenses*; *Blocks of Wood*; *Vertical Page of Print*

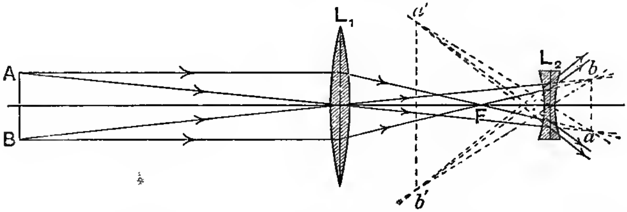
Place the page of print at the end of the room and set the convex lens parallel to it, as in the last experiment. By the method of relative motion make the needle coincide with the image of the print (for method see last experiment).

Between the needle and the convex lens place the concave lens at about its own focal length from the needle.

Remove the needle and look through the lenses at the print, keeping the eye close behind the concave lens. If the image is not distinct, move the concave lens slightly. Describe the image. The same principle is used in opera and field glasses, which consist of two Galileo's telescopes.

Note.—Instead of the print and needle, a candle flame and sheet of paper may be used, as in the previous experiments.

The diagram shows the paths of the rays: AB is the distant object; *ab* the inverted image which would be formed by the convex lens L_1, if the lens L_2 were away. If AB had been at a very great distance the image *ab* would have been formed almost at the focus F. L_2 is the concave lens, placed almost at its focal length in front of *ab*. *a′b′* is the upright virtual image formed by this lens.



EXPERIMENT **50**

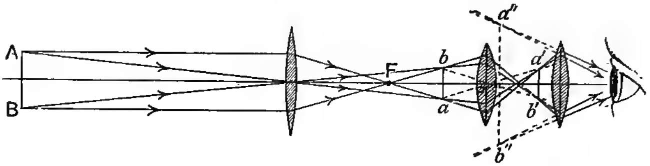
To construct a Model of the Terrestrial Telescope

Apparatus—*Double-Convex Lens, about* 30 *cm. to* 70 *cm. focus*; *Two Small Double-Convex Lenses,* 3 *cm. to* 5 *cm. focus*; *Stands*; *Blocks of Wood*; *Candle*; *Page of Print*; *Sheet of Paper*

In Exp. 48 you saw that the image formed by the astronomical telescope is inverted. This is not of much consequence when you are looking at a heavenly body, but in viewing bodies on the earth you want an erect image. This erect image is obtained by placing between the image *ab* and the lens L_2 (see diagram for Exp. 48) a double-convex lens L_3 of short focus. (In practice two double-convex lenses are usually interposed.)

Place a lighted candle at the end of the room, place the long focus lens as far away from it as possible, and obtain a distinct image of the flame on a vertical sheet of paper behind the lens.

Place behind the screen of paper one of the short focus lenses at the height of the image, and about twice its focal length behind the screen. This lens forms an erect image of the flame on the other side from the flame, and about the same distance from the lens as the inverted image is.



Place a vertical sheet of paper behind the second lens, and move it about till a distinct erect image of the flame is received on it.

Behind this screen place a second short focus lens at the height of the image and about 2 cm. behind it.

Remove the screen and look through the third lens at the flame, keeping your eye close to the lens. If the flame is not seen, then the lenses are not in a straight line or not at the same height. If the flame is not distinctly seen, move the third lens slightly till a distinct flame is seen.

Remove the flame and replace it with a vertical sheet of print, placing the print at the exact spot where the flame was. Look through the lenses at the print. If the experiment has been done carefully you should see an upright image of some of the printed matter.

The diagram shows the paths of the rays

CHAPTER VIII

DISPERSION OF LIGHT

EXPERIMENT **51**

To show that White Light can be Decomposed

Apparatus—60° *Triangular Prism*; *Large Sheet of Opaque Cardboard*; *Clamp Stand*; *Fish-Tail Gas Flame*

In a large sheet of opaque cardboard cut a vertical slit about 2 cm. long and not more than 2 mm. broad. Make the edges of the slit as smooth as possible.

Fix the sheet in a clamp stand with the vertical slit in front of a fish-tail flame. Turn the flame edge on to the cardboard and place the flame almost touching the slit.

Hold the prism with a refracting edge vertical, more than a metre in front of the slit, and look at the slit through the prism. Do you see the slit when you look straight through the prism at it? If not, what is the reason? If the refracting edge is to your left hand look through the prism to the left of the slit. When you do see the slit, what is its appearance? Name all the colours you see.

The row of colours is called the *spectrum*. The white light has been broken up or *decomposed*, or *dispersed* into the coloured lights.

EXPERIMENT **52**

To study the Spectrum[1]

Apparatus—*Same as that of Exp.* 51; *White Cardboard Screen*; *Convex Lens*, 15 *to* 30 *cm. focus, on stand*; *Blocks of Wood*

Fit up the apparatus as in Exp. 51. In front of the slit fit up a convex lens, parallel to the sheet of cardboard. Place the lens at a distance from the cardboard, a little more than the focal length, the principal axis of the lens passing through the centre of the slit.

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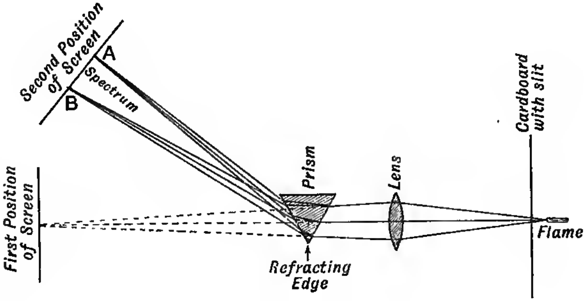
[1] This experiment should be performed in a dark room.

Set up a vertical screen in front of the lens, and move it away from the lens till a *distinct* image of the slit is seen on it.

Place a prism on a block of wood between the lens and the image on the screen. The refracting edge of the prism should be vertical, and the rectangular surface (or base) opposite the refracting edge should be at right angles to the sheet of cardboard (see diagram). The prism is in position when the image of the slit disappears from the screen.



The light which reaches the prism from the slit is refracted (in what direction ?). Move the screen round towards the base of the prism, keeping the screen at the same distance from the lens. In a certain position, a band of coloured light appears on the screen. Clamp the screen in this position.

Turn the prism slowly round on a vertical axis. What happens to the spectrum ? At a certain instant, while the prism is being turned, the spectrum stops and then begins to retrace its motion. This is the position of *minimum deviation.* (See Exp. 34.) Note that the spectrum is brightest when the prism is in this position.

Keep the prism at the position of minimum deviation and examine the spectrum. Name the colours from the left-hand side. Can you see the following: red, orange, yellow, green, blue, violet? [*Note.*—The blue is often spoken of as blue and indigo, but the two cannot be distinguished by the eye].

Which of the seven colours is refracted the least, and which the most? The coloured rays are said to have different *refrangibilities*, the red rays being least refrangible, and the violet rays the most.

EXERCISES

1. In the experiment, substitute a prism with a small angle for the 60° prism. Compare the length and the brightness of the spectra, also the refraction in each case.

2. Repeat the experiment with a broad slit. Is the spectrum as good as before? What must you have if you wish a good spectrum?

3. In the diagram of the experiment, rays refracted through the prism are seen to reach the screen in two bands A and B. What is the colour at A and what at B? Do any other rays reach the screen? If so, where?

4. Fix a sheet of cardboard (about 4 in. × 2 in.) vertically in a clamp stand, and introduce it between the prism and the screen close to the prism. Arrange it so that only the red is seen on the screen. Place another vertical prism between the screen and the first prism in the path of the light and rotate it till a band is seen on the screen. What kind of band is it? Is it narrower or broader than the first red band? Repeat with the violet band. Make a small hole in the screen where the red rays fall, and place another prism behind the screen so that the red rays pass through it. Place another screen to receive the rays after they have passed through the second prism. What do you see on the screen? [*Note.*—As the light reaching the prism from the lens is not strictly parallel, since the lens is not placed at its exact focal length from the slit, the spectrum is not a perfectly pure one—*i.e.* the colours overlap, so the band caused by the second prism may contain several colours.]

5. Set up the apparatus of the experiment and obtain the spectrum as before. Place a *thin* sheet of red glass in the path of the rays between the prism and the screen. What do you notice on the screen? What has happened to the other rays?

Keep the red glass in position and interpose a thin sheet of blue glass between the red glass and the screen. Is there any change? Remove the red glass. Place other coloured glasses in the path of the rays and note the effect of each. [*Note.*—If the glass is thick the rays reaching the screen are so faint as to be hardly visible.]

6. Set up the apparatus of the experiment, remove the screen and look into the prism so that you see the spectrum. Between your eye and the prism place a sheet of blue glass. What is the appearance of the spectrum? Are all the red rays stopped? Repeat with sheets of glass of different colours.

7. Look at a candle or gas flame through (1) a piece of red glass; (2) pieces of red and blue glass placed together; (3) pieces of red, blue, and green glass; (4) pieces of red, blue, green, and yellow glass. Explain the appearance in each case.

EXPERIMENT **53**

To form White Light from its Components

Apparatus—*Same as last Experiment*

Fit up the apparatus of last experiment and obtain the spectrum on the screen.

Between the prism and the screen place another vertical prism, having the same angle as the first prism. Arrange this second prism so that its surfaces are parallel to those of the first prism, but with its refractive edge towards the base of the first prism.

Place the second prism near the first one and move it till the spectrum disappears from the screen. Move the screen round towards its first position (*i.e.* the position before the first prism was placed between the lens and the screen). In a certain position you should see a bright image of the slit. The rays which were dispersed by the first rays have been recombined by the second prism to form white light.

Place a sheet of cardboard between the prisms and make sure that the first prism has really broken up the light.

EXERCISES

1. The coloured rays may be recombined in the following way: Fit up the apparatus of the experiment to produce the spectrum on the screen. Between the prism and the spectrum place a cylindrical jar, or a flask, filled with water (a gas collecting jar will do). Move the jar about till a white image of the slit appears on the screen. Between the prism and the jar insert a piece of cardboard so as to cut off the blue rays. What do you notice on the screen?

2. Rotate a Newton's disc (this consists of a circular piece of cardboard divided into seven equal sectors coloured (in order) red, orange, yellow, green, blue, indigo, violet). Cover one or more sectors with white paper and rotate again. What is seen now? Colour one half of a circular disc with red and the other half with bluish green. Rotate the disc rapidly. What is seen? One colour is said to be *complementary* to another when the two together produce white light. Thus red and green, dark blue and yellow, are complementary colours.

Note.—An ingenious arrangement of Newton's disc is sold by Perry & Co., 18-20 Holborn Viaduct, London, at 5s. By means of it many beautiful designs may be shown. It can also be used for experiments on sound.

A simple form of Newton's disc can be made from a popular toy called a "see-saw." It consists of a cardboard disc with two holes equidistant from the centre. Through the holes a string about a yard long is passed and the ends tied. This string is held in the hands, twisted, then pulled taut for an instant and let go. The result is to rotate the disc rapidly.

3. Allow the decomposed light which passes through the prism to fall on a concave mirror. Turn the mirror a few degrees round to one side. Place a small piece of paper attached to a pen-point in front of the mirror at the focus, and move it about till it receives the light reflected from the mirror. What is seen on the paper?

EXPERIMENT **54**

The Colour of Bodies

Apparatus—*Same as Exp.* 52; *Pieces of Coloured Cardboard or Paper*

Fit up the apparatus to form a spectrum on the screen. In front of the screen place a piece of white cardboard so that it passes in front of the coloured band. What is the colour of the paper? The colour is due to the reflection of the coloured rays from its surface.

Replace the white cardboard by black cardboard. What is its colour when placed in the path of the rays? The coloured rays are all absorbed by the black cardboard and none reflected to the eye, so the whole spectrum appears black.

Place now a red piece of paper (*e.g.* blotting-paper) in the path of the rays. What is the colour? Can you explain the reason?

Repeat with cardboard of other colours. From the experiment you will see that the colour of a body does not depend on the body itself, but on the kind of light which falls upon it and is reflected.

Exercises

1. Throw a little salt into a bunsen flame or a spirit-lamp so that the flame becomes an intense yellow. Examine in a dark room (1) your hands; (2) a piece of white cloth;

(3) a piece of red cloth. What is the effect of the yellow light on each?

2. Why is a rose red and a lily white? What would be the colour of each when a blue light falls on them?

EXAMINATION PAPER ON DISPERSION

1. Define *dispersion of light*, *spectrum*, *refrangibility*. How would you produce a spectrum?

2. A dress is bought in a shop where the gas is lit. When examined next morning it is found to be of a different shade. Why is this?

3. Describe carefully what you see when you look through a prism at a very small flame.

4. What are required to produce a pure spectrum? What is the use of each part of the apparatus? Sketch the arrangement of the apparatus.

5. Describe any method of recombining coloured rays into white light. Is it correct to talk of white rays?

6. A leaf is green and so is a piece of glass. Is the colour in each due to the same cause? Red light falls on the leaf and it appears black. Explain.

7. "Bodies have no colour of their own." What is the meaning of this statement?

8. Two narrow strips of coloured paper, red and blue, are placed together horizontally on a sheet of black paper. On looking at them through a prism they are found to be displaced, but the red strip is not so much displaced as the blue. What does this prove about the refrangibility of red and blue rays?

9. A light when viewed through one piece of glass appears red, and through another piece it appears blue. The two pieces of glass are then placed together. On looking through them the light can scarcely be seen. Why is this?

TABLES

I

UNIT OF ILLUMINATING POWER

The British Standard Candle is a spermaceti candle $\frac{7}{8}''$ diameter, weighing 6 to the lb., and burning 120 grains per hour.

II

INDEX OF REFRACTION (FROM AIR)

Solids

Diamond	2·45
* Glass (Flint)	1·60
Rock Salt	1·54
* Glass (Crown)	1·50
Fluor Spar	1·43
Ice	1·31

Liquids

Carbon Disulphide	1·63
Benzene	1·50
Olive Oil	1·47

Liquids—*continued*

Turpentine	1·47
Glycerine	1·47
Sulphuric Acid	1·43
Alcohol	1·36
Ether	1·36
Water	1·33

III

CRITICAL ANGLES (APPROX.)

Diamond	24° 30′
* Glass (Crown)	41° 45′
Carbon Disulphide	37° 45′
Benzene	42° 0′
Turpentine	43° 0′
Water	48° 45′

* The answers vary according to the specimens.

IV

SINES OF ANGLES

Degrees	0′	30′	Degrees	0′	30′	Degrees	0′	30′
0°	·000	·009	31°	·515	·522	62°	·883	·887
1°	·017	·026	32°	·530	·537	63°	·891	·895
2°	·035	·044	33°	·545	·552	64°	·899	·903
3°	·052	·061	34°	·559	·566	65°	·906	910
4°	·070	·078	35°	·574	·581	66°	·914	·917
5°	·087	·096	36°	·588	·594	67°	·921	·924
6°	·105	·113	37°	·602	·609	68°	·927	·930
7°	·122	·131	38°	·616	·623	69°	·934	·937
8°	·139	·148	39°	·629	·636	70°	·940	·943
9°	·156	·165	40°	·643	·649	71°	·946	·948
10°	·174	·182	41°	·656	·663	72°	·951	·954
11°	·191	·199	42°	·669	·676	73°	·956	·959
12°	·208	·216	43°	·682	·688	74°	·961	·964
13°	·225	·233	44°	·695	·701	75°	·966	·968
14°	·242	·250	45°	·707	·713	76°	·970	·972
15°	·259	·267	46°	·719	·725	77°	·974	·976
16°	·276	·284	47°	·731	·737	78°	·978	·980
17°	·292	·301	48°	·743	·749	79°	·982	·983
18°	·309	·317	49°	·755	·760	80°	·985	·986
19°	·326	·334	50°	·766	·772	81°	·988	·989
20°	·342	·350	51°	·777	·783	82°	·990	·991
21°	·358	·367	52°	·788	·793	83°	·993	·994
22°	·375	·383	53°	·799	·804	84°	·995	·995
23°	·391	·399	54°	·809	·814	85°	·996	·997
24°	·407	·415	55°	·819	·824	86°	·998	·998
25°	·423	·431	56°	·829	·834	87°	·999	·999
26°	·438	·446	57°	·839	·843	88°	·999	1 (approx.)
27°	·454	·462	58°	·848	·853	89°	1 (approx.)	1 (approx.)
28°	·470	·477	59°	·857	·862	90°	1·000	...
29°	·485	·492	60°	·866	·870	...	...	...
30°	·500	·508	61°	·875	·879	...	...	...

ANSWERS TO EXERCISES

CHAPTER I

Experiment 2

3. 16 sq. inches.
4. 8 cm.
5. 8 inches.

Experiment 4

4. 6 inches.

Experiment 5

2. 18 inches.
3. 20 cm.

CHAPTER II

Experiment 6

1. 6·9 cm.
2. 16.
3. 9 to 4.
4. 2 feet.
5. 4 candle power.

Experiment 7

2. 3 feet from the 9 c. p. lamp.

Experiment 8

1. 1 to 2 (approx.).

CHAPTER III

EXPERIMENT 10

5. (1) 14 cm.; (2) 28 cm.

EXPERIMENT 13

1. 35, 23, 19, 10, 7, 5, 4.

EXPERIMENT 14

3. 2 cm., 10 cm., 14 cm., 22 cm., 26 cm., etc., from left-hand mirror (measured to the left); 4 cm., 8 cm., 16 cm., 20 cm., 28 cm., etc., from right-hand mirror.

5. 4 primary, 8 secondary.

EXPERIMENT 15

2. 45°.

CHAPTER IV

EXPERIMENT 22

2. $u = \infty$; $\frac{1}{u} = 0$.

3. $v = u$.

EXPERIMENT 23

1. (1) 10 cm. behind mirror; (2) infinite distance in front; (3) 20 cm. in front of mirror.

2. 7·2 cm. behind mirror.

3. 8 feet.

4. Infinite (mirror is plane).

EXPERIMENT 24

2. (1) $1\frac{2}{3}$ cm. behind; (2) $6\frac{2}{3}$ cm. behind.

3. Convex; 6·25 cm.

Experiment 26

2. (1) $4\frac{1}{2}$ cm. behind, $4\frac{1}{2}$ cm.; (2) 36 cm. in front, 9 cm.; (3) 18 cm. in front, 3 cm.; (4) $13\frac{1}{2}$ cm. in front, $1\frac{1}{2}$ cm.

3. (1) 24 cm. in front of mirror; 12 cm. (2) 24 cm. behind the mirror; 24 cm.

4. (1) 8 times; (2) $5\frac{1}{3}$ inches.

5. 6 cm.

Experiment 27

1. 9 cm. (virtual image).
2. $2\frac{6}{7}$ cm.

Experiment 28

1. $6\frac{2}{3}$ cm. behind mirror; 4 cm.
2. $\frac{1}{2}$ focal length behind mirror; $\frac{1}{2}$ object.

CHAPTER V

Experiment 32

2. 8 inches.
3. $\frac{5}{4}$.
4. 2 cm. below top of slab.
5. Bring object 2 cm. nearer.

Experiment 34

1. Angle of refraction = half the angle of prism.
3. $15\frac{1}{2}°$ (approx.).
4. 1·51.

Experiment 35

6. 41° 30′.

CHAPTER VI

EXPERIMENT 42

1. (1) 2 feet from lens on opposite side from object; (2) 1 in.
2. 3 cm.
3. $6\frac{2}{3}$ cm.
4. 22·2 cm.

EXPERIMENT 45

1. Concave; 20·8 cm.

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